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**Natural
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Conservation
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Engineering
Field
Handbook

Chapter 13 Wetland Restoration, Enhancement, or Creation

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Preface

Chapter 13, Wetland Restoration, Enhancement, or Creation is one of the 18 chapters of the U. S. Department of Agriculture Soil Conservation Service (SCS) Engineering Field Handbook, previously referred to as Engineering Field Manual. This manuscript will supercede the previous document, Dikes and Levees-Wildlife Wetland Development. Other chapters that are pertinent to, and should be referenced in use with, Chapter 13 are:

Chapter 1: Engineering Surveys
Chapter 2: Estimating Runoff
Chapter 3: Hydraulics
Chapter 4: Elementary Soils Engineering
Chapter 5: Preparation of Engineering Plans
Chapter 6: Structures
Chapter 7: Grassed Waterways and Outlets
Chapter 8: Terraces
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Chapter 10: Gully Treatment
Chapter 11: Ponds and Reservoirs
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Chapter 14: Drainage
Chapter 15: Irrigation
Chapter 16: Streambank and Shoreline Protection
Chapter 17: Construction and Construction Materials
Chapter 18: Soil Bioengineering for Upland Slope Protection and Erosion Control

The science of wetland restoration, enhancement, and creation is rapidly evolving and improving. Therefore, additions to and modifications of Chapter 13 will be made as necessary.

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650.1300 Introduction

(a) Purpose and scope

This chapter provides field personnel with a guide for wetland restoration, enhancement, and creation. It describes the planning, design, implementation, maintenance, and monitoring phases of wetland restoration, enhancement, or creation projects of all sizes. However, the chapter is national in scope and should be supplemented with regional and local information. Policy and design criteria are contained in the Field Office Technical Guide (FOTG), Section IV, Standards and Specifications.

The wetland restoration, enhancement, or creation process involves more than an engineering approach. Therefore, the scope has been expanded beyond the traditional Engineering Field Manual (EFM) focus to address the necessary interdisciplinary nature of the total wetland ecosystem.

(b) Background

Wetlands form in three basic hydrologic systems: depressional, riverine, and tidal. Three critical factors govern the viability of a wetland ecosystem: hydrology, soils/geomorphology, and vegetation. These factors must be addressed in every wetland project regardless of its functions or purpose.

Wetland projects normally fall into one of these four categories:

Wetland restoration is defined as the rehabilitation of a degraded wetland or a hydric soil area that was previously a wetland.

Wetland enhancement is defined as improvement, maintenance, and management of existing wetlands for a particular function or value, possibly at the expense of others.

Wetland creation is defined as the conversion of a non-wetland area into a wetland where a wetland never existed.

Constructed wetlands are specifically designed to treat both non-point and point sources of water pollution.

Wetlands are dynamic ecosystems that often occur between deep water habitats and uplands. Some wetlands are wet year-round, and others are wet only seasonally. Although some wetlands are functionally similar, regional differences in the U.S. need to be taken into account. Listed below are six major kinds of wetlands are addressed by this manual. These categories are illustrated in figure 13-1.

(1) Leveed
Leveed wetlands are found in flat areas where water is supplied by gravity, pumping, or during high tides, but they are most common in irrigated cropland areas. They provide important habitat for wintering waterfowl and other wetland wildlife in California's central valley, on the gulf coast, east coast, and along streams in the Midwest.

(2) Pothole
Pothole wetlands of north central North America were formed in depressions left by retreating glaciers. They provide a majority of our waterfowl production habitat. They also provide critical forage and crops during drought periods when other land is too dry. Grasses, sedges, and other herbaceous vegetation generally dominate prairie pothole wetlands. Similar depressional wetlands, some formed by wind and other geologic processes, occur in the inter-mountain area of the Northwest.

(3) Floodplain
Floodplain wetlands of the Mississippi River drainage and along other large southeastern rivers originally were dominated by stands of mixed bottomland hardwoods interspersed with deeper herbaceous wetlands in remnant river channels and sloughs.

(4) Freshwater
Freshwater wetlands of the Northeastern U.S. are usually found in depressions left by retreating glaciers. Included are emergent, scrub-shrub, pocosins, and wooded wetlands, which have evolved based on water depths and soils. Similar wetlands are found in depressions created by various geologic processes throughout the East.

Figure 13-1 Six major kinds of wetland

Figure 13-1a Leveed

Figure 13-1b Prairie potholes (restored) (U.S. Fish and Wildlife Service photo)

Figure 13-1c Floodplain

Figure 13-d Freshwater wetlands of the Northeastern U.S.

Figure 13-1e Riparian

Figure 13-1f Depressional

(5) Riparian
Riparian wetlands occur along creeks, streams, waterways, seeps, and springs. However, not all riparian areas are wetlands.

(6) Depressional
Depressional wetlands of the arid and semi-arid West (playa lakes, vernal pools) generally hold water for short periods during the winter and spring. During these periods they provide important habitat for wintering and migrating wetland birds and some amphibians, and they can provide for the replenishment of soil and ground water.

No attempt has been made in this chapter to address other types of wetlands that require special consideration or are generally more difficult to restore, enhance, or create, such as alpine wetlands, salt and brackish water wetlands, mountain meadow wetlands, permafrost wetlands of Alaska, floating bogs, and the rain forests of Hawaii and Puerto Rico. However, many of the techniques presented in this chapter can be applied to these wetlands.

Also beyond the scope of this chapter is the design of constructed wetlands for waste water treatment from acid mine drainage, cropland runoff, feedlot runoff, municipal sources, or other sources of contaminants. Certain portions of the chapter will provide techniques to be used in the planning, design, and implementation of these wetlands. However, regional or local specialists should be consulted for guidance in working with these wetlands because contaminant concentrations create special hazards.

(c) Information and agency sources

Several Federal agencies, state natural resources agencies, and a number of private conservation groups publish pertinent information that has been used as background information for this chapter. A bibliography has been included as an appendix. Among the Federal agencies that contributed to this chapter were the Soil Conservation Service (SCS), the U.S. Army Corps of Engineers (USACE), the Fish and Wildlife Service (FWS), the Environmental Protection Agency (EPA), the Forest Service (FS), Tennessee Valley Authority (TVA), and Office of Surface Mining (OSM).

650.1301 Wetland processes and characteristics

Wetland processes and characteristics can be divided into three categories: physical, chemical, and biological. It is important to understand these processes and characteristics to set planning goals and to design and maintain the wetland system.

(a) Physical

(1) The water budget
A water budget for a wetland is an account of the inflow, storage, and outflow of water. Water inflow includes precipitation, storm water runoff from a contributing drainage area, base flow from streams and surface sources, seepage and springs from ground water sources, tidal inflow, and water artificially added to a wetland. Water storage includes the water on the surface and in the pore spaces of the substrate. The wetland substrate is the accumulated organic matter and the soils from the surface of the wetland to the bottom of the potential rooting zone. Water outflow includes evaporation from the surface, transpiration from the plants, deep percolation below. the substrate, surface base flow, tidal outflow, storm water outflow, and water artificially removed from a wetland.

(2) Sedimentation
Sedimentation is a term used to describe the process whereby sediment carried in the inflow water is deposited in the wetland. This deposition occurs because the velocity of the water carrying the sediment slows as it flows through the wetland, thus causing the suspended particles and bedload to drop out. Over time, this deposition changes the physical characteristics of the wetland. The accumulation of sediment decreases the available surface water storage capacity, affecting both the depth of water in the wetland and possibly the rate and amount of water that continues on downstream. These changes in the wetland can have a significant impact on the type of plant and animal community supported by the wetland.

(b) Chemical

(1) Redox potential

Redox potential is a measure of the potential electron exchange in the soil. When wetland soils become saturated, the diffusion of free oxygen through the soils is drastically reduced, and if organic matter is present for microbial consumption, anaerobic conditions will develop. Under anaerobic conditions, various ions (such as NO^{3-}, Mn^{4+}, Fe^{3},) gain additional electrons and are changed to other forms. This process of gaining electrons is called reduction and is mainly due to microbial activity. In soils, redox potential and pH are interrelated. Under reduced conditions, soil acidity may be temporarily consumed, and the pH of the reduced soil may tend toward a more neutral pH. If the wetland soil is drained, it becomes oxidized and will generally revert to the more acid condition.

(2) Nitrogen

Wetlands are very important in cycling nitrogen. As the dissolved nitrogen in the water passes through a wetland, much of it is captured and transformed by microbes. Plants take up nitrogen as they grow and release nitrogen as they decompose. Because nitrogen maybe the most limiting nutrient for plant growth in flooded soils, excess nitrogen can contribute to eutrophication or rapid plant growth. Nitrogen can leave a wetland with the water outflow. Because of the anaerobic conditions of wetland soils, much of the nitrogen becomes a gas and escapes to the atmosphere. The process of nitrogen loss is called denitrification.

(3) Iron and manganese

The reduced forms of iron and manganese in wetland soils are more soluble and, therefore, available to organisms. Reduced iron in wetland soils gives the soil a gray to green or bluish green color, with the green or bluish green indicating the most reduced cases. In aerobic zones, bacteria promote the oxidation of iron and manganese to more insoluble states.

(4) Sulfur

Oxidized sulfur can enter wetlands through precipitation and runoff. As the sulfur is reduced, it can form hydrogen sulfide gas that has a “rotten egg” smell. Sulfides and iron combine to form ferrous sulfide, which makes some wetland soils black. Oxidation of reduced sulfur in wetlands can create extremely acid conditions.

(5) Carbon

Carbon dioxide gas is converted into organic carbon by plants during photosynthesis. As organic matter decomposes in wetlands, some of the carbon is transformed into acids, alcohols, and methane gas.

(6) Phosphorus

Most phosphorus is transported to wetlands with sediments. Excess phosphorus can contribute to eutrophication. Phosphorus taken up by the plants is released as plant debris decomposes. In anaerobic conditions, phosphorus is more likely to form soluble compounds and can be removed from the wetland with the water.

(c) Biological

(1) Microbes

Microbes play a major role in the transformation of substances critical to all life on earth. In wetlands, the population of microbes in the substrate shifts from aerobic species near the surface to anaerobic species as depth increases. Aerobic microbes also continue to function in the thin, oxygen-rich zone called the rhizosphere surrounding the roots of wetlands vegetation and at the water surface. Mycorrhizial fungi are beneficial microbes that facilitate nutrient uptake, reduce stress, enhance salt and contaminant tolerance, and enhance the initial survival and growth of wetland plants.

(2) Vegetation

Wetland vegetation may be described as floating, rooted, emergent, submergent, herbaceous, or woody. Wetland plants transport oxygen from the leaves through the stem to the roots. Radial oxygen loss from the roots creates an oxidized zone in the soil immediately surrounding them. The value of microbes to vegetation is described above. Wetland vegetation also traps sediment and removes nutrients and pollutants from the water column and soil. Wetland plants produce more biomass per acre than any other species group and export huge quantities of detritus to aquatic systems, providing direct benefits to the food chain.

(3) Animals

Wetlands provide water, food, and shelter for many species of animals, including many threatened and endangered species. Wetlands support invertebrates, fish, amphibians, reptiles, birds, and mammals. Many species typically not recognized as wetland residents spend some part of their life cycle or fulfill daily requirements in wetlands. Species such as the beaver and muskrat can alter wetlands by their activities.

650.1302 Planning and site selection

(a) Define objectives and purpose

The objectives and goals of any wetland project must be defined in the early stages of the planning process. These goals will reflect the desire to restore, enhance, or create one or more of the wetland functions described in table 13–1. Planning should be oriented toward restoration, enhancement, or creation of an ecologically, biologically, and hydrologically functional system. Objectives should encompass regional and hydrologic unit priorities whenever possible. An understanding of how the wetland functioned in its natural, undisturbed condition should also be considered. Individual wetlands are part of larger wetland complexes that must be addressed in planning and site selection.

In siting target areas to achieve desired objectives, inventories should address both quantity and quality of resources and should locate and identify existing, altered, or lost wetlands. For example, target groups of wildlife or fish, or target functions such as water storage or sediment control, can be more readily achieved if past resources and functions are known. This will mean identifying any human-induced change that disturbed or altered natural wetland systems.

Sources of information that should be reviewed include the Fish and Wildlife Service's National Wetland Inventory maps, state wetland inventory maps (SCS), U.S. Geological Survey Topographic Quadrangle maps, geographical information system (GIS) data from Federal and state agencies (fig. 13-2), and wetland status and trend information from various agencies and groups. Historical aerial photography, such as Agricultural Stabilization and Conservation Service (ASCS) crop compliance photography and county soil survey information, can be useful in identifying hydric soils, drained wetlands, and various wetland types that may be difficult to detect otherwise. Floodplain elevations can often be determined from sources such as the Federal Emergency Management Agency. Landuser input may be the best source of information for assessing prior hydrologic conditions, the value of the lost wetland functions, and the feasibility of restoration or creation. By combining information from various sources, pre-existing hydrology and existing drainage systems can be analyzed and documented on a restorable wetland site.

Landscape ecology offers a means of looking at the landscape comprehensively to determine the consequences of wetland restoration, creation, or enhancement. An understanding of how a landscape composed of diverse ecosystems is structured, how it functions, and how it changes allows issues such as habitat fragmentation and biodiversity to be addressed (fig. 13-3). More information regarding this ecological planning approach can be obtained from the Landscape Ecology Journal. Dr. Frank B. Golley, University of Georgia Athens, Georgia , is current Editor-in-Chief of this journal. A key factor in this approach to planning and design is that wetlands are part of an interconnected landscape of ecosystems of which humans are an integral component.

In general, restoring degraded wetlands within a complex of existing wetlands will have the greatest chance of success. This is because there is a greater chance of pre-existing hydrologic soil conditions; better biological conditions such as seed-containing soils; and faunal recovery possibilities from adjacent areas. Wetland enhancement will involve improving wetland functions and values. Planners should assess the effects of targeted enhancement on the wetland's other functions and values. Wetland creation may involve such constraints as poorly suited soils, insufficient water supply, and lack of desired plant material, rendering the process more difficult and expensive.

When investigating wetland functions, regional, watershed, and decisionmaker objectives should be considered in setting priorities for restoration, enhancement, or creation. Table 13-1 lists 15 functions and provides descriptions, function interactions, and planning/design considerations for each function. Examples of multifunctional wetlands are shown in figure 13-4.

(b) Site evaluation

Data collection is the first phase of site evaluation in planning a wetland project. The information obtained is often used to determine feasibility of the project. The necessary data should be collected as early as possible in the planning process. The level of data collection will depend on the complexity of the proposed project.

Figure 13–2 GIS data aids planning and site selection

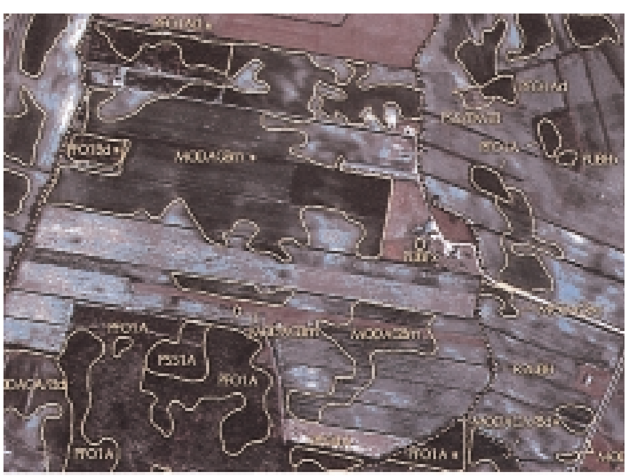


Figure 13–3 Landscape ecology takes landscape structure, function, and related changes into account

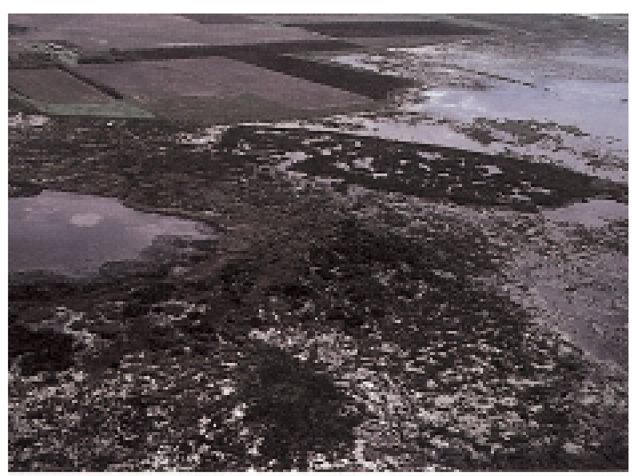


Figure 13–4 Wetlands serve multiple functions and values

Figure 13-4a Erosion and sediment control and water quality (U.S. Fish and Wildlife Service photo)

Figure 13-4b Education, recreation, cultural, and aesthetic quality

Figure 13-4c Shellfish, open space, flood conveyance and habitat for threatened or endangered species

Figure 13-4d Wildlife habitat, archaeological, and flood storage

Table 13-1 Wetland functions

Function	Description	Function interactions	Planning/design considerations
Education and research	Wetlands are unique and highly productive ecosystems that provide excellent opportunities for nature observation, education, and scientific research.	Education and research activities are generally compatible with other functions, although they may be limited or constrained by other uses. Human activity may at times impair use by wildlife, particularly for sensitive species during critical times of the year.	Specific design criteria may only be needed where special landscape features, structures, and facilities must be constructed to accommodate educational objectives. Design specifications are available from the National Park Service, Corps of Engineers, Fish and Wildlife Service, and state parks or educational departments. Accommodation for research usually doesn't require permanent facilities, but in some cases may have unique design requirements or may require rules to regulate destructive sampling.
Erosion control	Shoreline vegetation in coastal wetlands and those inland wetlands adjoining lakes and rivers reduces the impact of storm tides and waves before they reach upland areas. Wetland vegetation also reduces bank erosion along streams. Often vegetation is used with structural measures.	Stabilization of stream, lake, and reservoir banks and shorelines with wetland vegetation can benefit many other uses, primarily through reduction of sediment and improved water quality. In addition, wetland vegetation installed for erosion control can provide habitat for wildlife, improve aesthetic and recreational values, and protect the adjoining uplands from erosion.	Wetlands provide erosion control through two basic mechanisms: soil stabilization (vegetation establishment, roots) and energy dissipation of waves, tides, drawdowns, and stream flows. Wetland vegetation for erosion control, usually located in high energy environments, often requires protection during establishment. In very high energy environments, permanent or semi-permanent structures (i.e., rock riprap, pipe and wire revetment, gabion blankets) may be required to provide a stable environment for wetland vegetation.

Table 13-1 Wetland functions—*Continued*

Function	Description	Function interactions	Planning/design considerations
Fish and shellfish production or habitat	Wetlands provide habitat, especially spawning habitat and nursery areas, for fish, shellfish, and shrimp. They also provide habitat for aquatic invertebrates which are essential food for fish and shellfish.	Fish and shellfish require permanent water of good quality. They can be important sources of food for humans and wildlife and provide for recreation activities. Vegetation removal for food production and wood products can be done in a manner compatible with fish and fishing. Other wetland functions, such as habitat, water quality, historic, cultural, archaeological, education and research, open space and aesthetic quality, are generally compatible with the requirements of fish and shellfish, if considered during planning and design. Conversely, sediment control, erosion control, flood conveyance, flood storage and timber production have a higher potential for incompatibility.	Permanent water is needed to maintain fish populations. Facilities for complete drainage may be necessary to allow for harvest or future control of undesired fish. Resident populations require 3 to 10 foot water depths with varied bottom topography. Wetlands for breeding and nursery habitat and detrital food production should be less than 3 feet deep and adjacent to associated deep water habitats. Water quality is the key to survival and the production of fish and other aquatic organisms. Each species has its own specific requirements. Conservation practices should be employed to control deposition of sediment from watershed erosion to prolong functionality of the area.
Flood storage	During peak runoff, rivers and streams overflow into floodplains. Wetlands in floodplains retain overflow and reduce rate of flow through slow release. Isolated wetlands outside of the floodplain also hold runoff and contribute to flood control.	Many flood storage reservoirs provide aesthetic wetland habitat, and others have incorporated various types of recreational facilities, trails, picnic areas, playgrounds, observation platforms, and fishing and boating facilities. Numerous smaller wetlands in a watershed can cumulatively have a significant effect on flood water storage. Flood storage reservoirs overlying coarse textured soils and permeable substrates can also benefit ground water recharge.	Design requirements are similar to flood conveyance, but often less restrictive. Roughness caused by trees and shrubs, as well as other effects, such as reduced stream capacity, are not as critical within flood storage reservoirs. Rapid water level fluctuations are a major constraint to wetlands especially in western reservoirs.

Table 13-1 Wetland functions—*Continued*

FFunction	Description	Function interactions	Planning/design considerations
Flood conveyance	Floodplain wetlands often are natural floodways that convey flood waters from upstream to downstream points.	Flood conveyance can be compatible with many other uses or it can be a significant constraint. Where design and construction are limited by space or other factors, and vegetation is limited to herbaceous growth, its value for wildlife, fish, recreation, or aesthetics can be very limiting. Where design and construction is less constrained and allows greater vegetative diversity, including woody riparian vegetation, these values can be much enhanced.	Individual wetlands or multiple wetland projects seldom provide sufficient land area to significantly increase flood conveyance along waterways or rivers. Designs for floodplain wetlands adjacent to rivers and waterways must consider local flood conveyance requirements. For example, the decision as to whether the flood conveyance should include flow retardance/ roughness provided by herbaceous, shrub, and/or tree types of vegetation will dictate design requirements. Maintenance of vegetation at design water levels is also a key consideration. Flood conveyance can incorporate a complex of trees, shrubs, and herbaceous vegetation.
Food production	Wetlands may produce animals or plants for use as human food or to provide forage for domestic livestock.	Where wetlands are managed primarily for human food or livestock feed, competition with wildlife is often not desired and is constrained by management. Proper livestock grazing can be used as a wetland vegetation management tool with more desirable effects than is obtained from prescribed burning, herbicides, disking, or other management techniques which tend to remove vegetation completely. Other wetland functions which are dependent upon more stable wetland conditions are generally subject to adverse impact by food production activities.	Incidental food production: The specific requirements (water depth, hydrologic cycle) for each desired species needs to be considered. Grazing and hay: Normally only applicable in seasonally dry wetlands. Timing and intensity of use should be regulated so as not to adversely affect other desired functional values. Generally, livestock should be excluded from permanently wet areas including streams or from seasonal wetlands during wet periods.

Table 13-1 Wetland functions—*Continued*

Function	Description	Function interactions	Planning/design considerations
Habitat for threatened and endangered species	Wetlands provide critical habitat for Federal and state listed threatened and endangered species.	Management for threatened or endangered species of plants or animals can often exclude or limit management of wetlands for other uses, even other wildlife resources. Management for other functions, such as waterfowl hunting, water storage, flood control, open space, or aesthetic quality, may allow production of an endangered species, such as a plant, which is compatible with the other uses. Excessive human activity may adversely affect an endangered species, especially at certain times of the year, such as when nesting is occurring. This may preclude or limit activities involving human uses such as recreation.	Specific requirements of targeted species of animals or plants must be considered. Recovery plans and other information on the species must be referred to for habitat needs and design requirements.
Historic, cultural, and archaeological	Some wetlands are of archaeological interest. Early settlements were located near wetlands and deepwater habitats, which served as sources of fish, shellfish, waterfowl, and plants for food. Wetland plants were often used for making baskets, boats, and other items. Many northeastern and other wetlands figured prominently in combat among Indians, English, and French settlers and influenced early historical patterns of community growth and communication.	Preservation of archaelogical and historical resources can often be incorporated along with other functions of wetlands. Archaeological sites covered by water, a shallow soil layer, or certain vegetation, for example, may not adversely affect some artifacts. On the other hand, covering an area with a dam, removal of soil during construction, or timber harvest can severely damage archaeological artifacts unless removed and moved to another site.	In reservoirs or wetland sites, these areas can in some cases be covered by water or shallow layers of soil and wetland vegetation. Some sites may need specific access provided, similar to recreation areas. Should historic, cultural, or archaeological features be a wetland goal or objective, extreme care should be taken to coordinate with local authorities, State Historical Preservation officers, and native tribes. Many cultural resource sites have been deliberately protected by capping or covering with water as part of the design.

Table 13-1 Wetland functions—*Continued*

Function	**Description**	**Function interactions**	**Planning/design considerations**
Open space and aesthetic quality	Wetlands can contribute significantly to aesthetic quality and open space. As highly visible ecological features, wetlands are often perceived as remnants of the naturally occurring landscape that make land aesthetically pleasing and reflect a stewardship ethic. People seeking places for vacations, driving for pleasure, and other recreational pursuits are attracted to aesthetically pleasing wetlands and the open space they add to the landscape.	Aesthetic quality and open space are generally very compatible with other functional uses. Timber production, sediment control, flood conveyance and associated activities may so impair the area's condition, however, as to seriously degrade aesthetic quality or preclude open space. Other wetland functions, such as wildlife habitat, education and research, historic and cultural, and water quality, often provide the attributes prerequisite for high aesthetic quality	Aesthetic quality and open space are generally natural products of wetland restoration, enhancement, or creation. Planning and design for these and other wetland functions must take into account the effect and compatibility of alternatives with overall landscape. Basic determinants of aesthetic quality must be considered and manipulated through planning and design to achieve stated objectives.
Recreation	Wetlands can serve directly or indirectly as a recreational attribute. Activities include hunting, fishing, boating, hiking, horseback riding, bird watching and photography, and general enjoyment of the aesthetic qualities of a natural environment.	Recreational activities are generally very compatible with other functional uses; however, season of use and number of visitors may be limited by other functions. Flood control and wildlife nesting or breeding may restrict human use during peak flood periods or nesting and breeding seasons. Other functions, such as timber production and sediment control, may also place restrictions on recreational uses.	Specific requirements for desired experiences and levels of activity must be considered during the design phase, as must the type of materials and construction methods that are compatible with other wetland resources. Recreation design includes special features, such as walkways, paths, visitors centers, fishing piers, and jogging trails. Design specifications are available from state recreation handbooks, the National Park Service, Corps of Engineers, Fish and Wildlife Service, and state parks or educational departments.

Table 13-1 Wetland functions—*Continued*

Function	Description	Function interactions	Planning/design considerations
Sediment control	Reduction of the velocity of water flowing through a wetland causes the deposition and entrapment of sediment.	Use of wetlands for sediment entrapment can benefit many other uses through improved water quality downstream. Unless removed periodically, however, sediment can accelerate the succession of wetland to upland. The associated impacts to the wetland site can seriously impair its suitability for serving other functions over the long term. Corrective measures to remove sediment periodically can adversely impact other functional values such as wildlife habitat, historical or archaelogical significance, fish, aesthetic quality, and recreation.	Wetlands for sediment control must consider sediment load and delivery anticipated over the life of the project, or include periodic removal and proper disposal considering sediment classification and sediment characteristics.
Timber production	Under proper management, forested wetlands can be an important source of wood products while protecting other functions and values.	Production of wood products can provide valuable habitat for wildlife as well as significant aesthetic and recreational values. The habitat needs of rare or endangered species should be carefully considered in planning any harvest or timber management activity. Numerous species thrive best in a diverse forest condition.	Wooded wetland plantings such as bottomland and hardwoods and stream riparian areas can be planted to provide site stability and fish and wildlife habitat improvement, with the intent of timber harvest. It is important to plant or assure the natural revegetation of several key indigenous cover and food producing species that will encourage and provide habitat diversity because of the long span of time before timber harvest will be realized. The effect of timber production practice on wetland functions, the landscape setting, and the needs of the landowner must be carefully considered to maximize benefits.

Table 13-1 Wetland functions—*Continued*

Function	Description	Function interactions	Planning/design considerations
Water supply	Wetlands are a source of ground and surface water that aid areas with dwindling water supplies. They store precipitation and runoff for direct or indirect use by humans, livestock, or fish and wildlife.	Storage of surface or ground water is compatible with other wetland functions. While serving this function, a wetland can provide habitat for fish, wildlife, and endangered species; offer aesthetic quality; and provide recreation and related opportunities. Sediment and contaminants can adversely affect water supply, and withdrawing water from wetland areas can adversely affect fish and wildlife habitat and other functions.	Surface water supply: Impermeable, or nearly so, substrates are needed (existing soil conditions or created by sealing). Because of the large volume of water needed for most uses, deep water ponds with a fringe of wetlands may be planned. Ground water recharge: Permeable substrate is a necessity.
Water quality improvement	Physically, filtration and sedimentation remove sediment and attached contaminants. Chemically, organic sediments raise the pH of acid mine drainage, resulting in precipitation of heavy metals. Biologically, microbes in the substrate and the rhizosphere capture soluble contaminants, and macrophytes raise the dissolved oxygen by transferring oxygen to the water. Growing vegetation will remove nutrients from the water, and if the vegetation is removed the net result is a reduction of nutrients.	Associated benefits include lower sediment load, improved aquatic habitat, enhanced aesthetic and recreation quality, and improved water quality for water supply. Concentration of toxic and nuisance substances may preclude or impair other wetland functions.	Design of wetlands for water quality should be influenced by the concentration of the contaminants in the influent, treatment objectives, and realistic performance expectations. The effectiveness of the wetland will be increased by spreading the influent over the wetland, eliminating stagnant areas, and increasing the detention time. Consult local or regional specialists. Harvesting or removal of vegetation might be needed to reduce pool of accumulated nutrients or for maintenance purposes.

Table 13-1 Wetland functions—*Continued*

Function	Description	Function interactions	Planning/design considerations
Wildlife habitat	Wetlands provide breeding, nesting, feeding, and cover for amphibians, reptiles, birds, and mammals.	Wildlife can be a primary or secondary use of wetlands. Wetlands primarily created, restored, or enhanced for other uses can provide compatible habitat for wildlife. Aesthetic quality, open space, flood storage, and historic, cultural, or archaeological values and functions are generally compatible. Careful monitoring of water withdrawn for water supply and vegetation removed for food or wood products, as well as sensitive use of wetlands for recreational education, can be mutually beneficial for both humans and wildlife. Indiscriminate use of wetland resources can adversely affect wildlife.	Design wetlands to provide water at the correct depth, time, and duration to promote desired vegetation; make it accessible (e.g., depth of water for dabbling ducks is less than 1 foot deep while divers need up to 10 feet deep or more) and provide other habitat elements required for the targeted species of wildlife. Habitat requirements for water, food, cover (for protection from adverse weather and predators), and reproduction (mating, nesting, brooding) should be considered. Migration corridors may be a concern, as are the effects of disjunct or widely dispersed habitats. Species requirements and habitat design elements are detailed in SCS Field Office Guides, plant and animal reference sheets, and numerous other references.

As a general guideline, the following items may be needed:

- Survey landscape context to determine landscape corridors that link habitat areas such as stream zones, ephemeral wet areas, woodlots, and others.
- Site investigation of soils to determine permeability, texture, slope, and hydric soil boundaries.
- Soil testing for nutrients, pH, and possible contaminants (residual pesticides, heavy metals).
- Watershed information such as drainage area, channel slopes, water storage capacity, location of depressions or potholes.
- Existing drainage systems.
- Existing and converted wetland areas and boundaries.
- Engineering and topographic surveys.
- Vegetative surveys, including elevations and species noted in the area.
- Fish and wildlife habitat evaluations.
- Threatened and endangered species habitat evaluation.
- Landscape use and aesthetic quality evaluations.
- State, Federal, and local regulations.
- Water quality data.
- USGS topographic maps or aerial photographs.
- Sources of nonpoint source pollution, such as upland sediment delivery.

More complex projects may require additional information, such as a complete ecological or economic analysis. Intensity of the analysis should be commensurate with project complexity. More intensive evaluation normally is needed when new wetlands are created.

Restoration, enhancement, or creation of wetland systems may require multiple landuser contacts and group planning to ensure system integrity. For example, installing water control structures in group drainage systems will require cooperation among those landowners affected. This cooperation must also extend to the restoration or management of the wetland complexes. An initial evaluation of potential sites utilizing the above checklist can best ensure success.

Additional discussion of some of the items to be considered follows:

(1) Soils

Soils at the site of the proposed wetland must be assessed for overall suitability. Water holding capabilities are influenced by soil texture, which will determine length of inundation. Organic matter and pore size distribution are also important. Clays and loams generally retain moisture longer than sands and sandy loams. The coarse textured soils may result in having “drier” plant communities, depending on water level. The soil’s general ability to support biological functions should be considered as well as the limitations of the soils for establishing the desired plants. The soil survey or soils information located in Section II of the FOTG provide interpretations for wetland vegetation.

The suitability of the soils as potential construction material should also be considered, including off-site soils that may be brought in from borrow sites. For example, dispersive clays, if uninventoried, may appear suitable and ultimately result in failure. If onsite excavation will occur, the stability on the side slopes must be considered. This information is also available in the soil survey or FOTG.

Soil characteristics should be assessed when it is likely that soil will be moved. If structural work is anticipated, need for and suitability of topsoil to revegetate the completed structure may require plans for stockpiling and respreading. It may also be necessary to locate a source of suitable soil for fill material on or off the site. Anticipated excavation and/or disposal of soil will require evaluating the soil for use as islands or landform buffers, or for safe disposal by spreading, safely stockpiling and vegetating, or hauling offsite. In the planning process, an inventory of available equipment may also be needed to identify all soil handling capabilities.

During the site evaluation of the soils, any suspected sod contaminants should be analyzed. Often, this will require a soils test performed by the State agricultural extension service or a private laboratory based on known or suspected contaminants that might be present in an area or region. Arsenic may be found in orchard sites and in areas where cotton has been grown. Selenium and boron, in some areas, are naturally high in concentration and may cause plant toxicities and can disrupt food chains and reduce targeted population densities. Sites where contaminants are found must be avoided or precautionary measures taken.

(2) Water

Hydrologic conditions directly affect chemical and physical soil properties such as nutrient availability, substrate anoxia, and pH. Even modest changes in hydrologic conditions may result in significant changes in plant and animal species diversity and productivity. Therefore, the watershed and surrounding geomorphology of the proposed wetland site must be inventoried and evaluated.

In evaluating the suitability of a site, the source of the water that will supply the wetland must be carefully considered. Wetlands can comprise only that portion of a watershed where the surface water is available or where the ground water table lies at or near the soil surface. Proper amounts of water needed must be available on the site during proper times of the year. In some instances, a site may be selected that will require pumping or diverting of water from an off-site source. Whenever possible, these sites should be selected in areas where water can be provided in an energy-efficient manner by surface water or flow from an adjacent natural or manmade water source. Processes that require large amounts of energy, such as using pumped ground water as a primary water source, should be avoided because of high operation and maintenance expense. Using surface waters from off-site sources may require permits in several States and may be affected by water rights laws.

(3) Vegetation

As soon as plans are relatively firm for the type and location of the wetland to be restored, enhanced, or created, decisions need to be made regarding vegetation for the wetland. Based on objectives, site conditions, budget considerations, and seed availability, plantings may not be necessary. Appendix A contains a checklist which provides a general guide to planning considerations for inventorying plant resources and plant community conditions, as well as other planning considerations that will address wetland function objectives for the site. The determination of plant species values for wildlife food and cover and erosion control can be found in the FOTG and other field office reference materials. It should include an assessment of land cover patterns that support species movement to and from the wetland site. This will indicate how the wetland site fits into a larger pattern of habitats.

(4) Wildlife and fish

Baseline data collection and site evaluation for wetland wildlife and fish can usually be accomplished by relatively simple techniques. However, larger projects may require a Wetland Evaluation Technique (WET), Habitat Evaluation Procedure (HEP), or other programming procedures to be conducted by field personnel to document pre-project conditions. WET is an Army Corps of Engineers (developed in conjunction with the Federal Highway Administration and Environmental Protection Agency) step-wise procedure for evaluating natural or manmade wetlands, based on wetland functions. It includes an IBM compatible software package available upon request from the Army Corps of Engineers, Waterways Experiment Station. The package is based on species profiles and habitat indicator guides. A manual and instructions are available upon request from U.S. Fish and Wildlife Service, Fort Collins, Colorado, research center. A similar step-wise habitat appraisal procedure based on targeted wildlife species is available from SCS for use on UNIX or DOS-based computers.

For special fish and wildlife baseline data needs, refer to SCS Technical Guides, U.S. Fish and Wildlife Service Endangered Species Recovery Plans and other sources listed as references.

(5) Problem plants and animals

Restoring or creating wetlands will attract new or increased numbers of plant and animal species that may cause problems, especially in or near urban areas. In planning, the effects of these new populations should be considered to prevent future problems. Large numbers of ducks and geese will damage lawns and other landscaped areas of nearby residents. Overuse by waterfowl can damage community parks or make them unpleasant to humans, and large numbers of waterfowl can adversely affect the quality of water supply reservoirs. It would not be prudent to locate wetlands that attract large numbers of geese near urban airports. Wetlands that may receive a high nutrient loading can become a source of unpleasant odors.

Most areas of the country have introduced and native plant and animal species that may adversely impact desired functional values. Listed below are some of the more common problem species and planning considerations for their control.

Mosquitoes, which breed in shallow water where they are safe from predators, are often a problem, especially in or near urban areas. If the wetlands are designed to maintain fish, mosquitoes will not be a problem unless there are extensive areas of shallow water, less than 6 inches deep, with fine-stemmed vegetation. In most cases, drying up shallow water areas during summer will control mosquitoes while encouraging better seed-producing waterfowl plants. Where mosquitoes are a problem in wetlands, permanent populations of mosquito fish *Gambusia affinis*, commonly called gambusia, can be stocked within their range to provide natural control. Gambusia can often be obtained from a local vector control agency or seined from a nearby pond. Before introducing any species of fish, careful consideration should be given to possible adverse impacts on populations of native species. Mosquito control is not recommended in areas where waterfowl production is important because mosquito larvae are an important part of the diet of some laying hens and most ducklings or goslings. However, mosquito control may be necessary adjacent to urban areas.

Carp and other rough fish can invade a wetland and destroy the aquatic plant community, reducing populations of desirable plant and animal species. Although Carp populations can be reduced by netting, the most effective method of control is to draw down the water completely and allow the bottom sediments to dry. Special care must be taken to be sure that small pools of water do not remain when a complete drawdown is needed.

Some species of vegetation can become very prolific and cause problems in achieving planned wetland functions and values. For example, cattails can cover an entire shallow (less than 2 ft. deep) wetland, eliminating other desirable vegetation or open water habitat for waterfowl. However, dense stands of cattails can also provide water quality benefits by removing nutrients and pollutants, and they provide habitat for some species, such as the yellow headed blackbird. The planned function and value of the wetland must be considered before deciding upon vegetation control (fig. 13-5). Vegetation can be controlled chemically, but in areas where it may become a problem, structures need to be planned that facilitate complete drainage and tillage of the bottom, or that allow water depth to be increased by at least 3 feet for a growing season. In addition, muskrats can be used to control vegetation.

Beavers are a possible nuisance animal. Beavers can cause a designed wetland function, such as flood storage, to be lost. Adjacent to urban areas, beavers will eat shrubbery and ornamental trees. The best defense against beaver invasion is to select vegetation beavers do not like. Consider using screened culverts and water control structures with anti-beaver devices, or installing drains that prevent beavers from controlling the water level.

Figure 13-5 Planned wetland functions and values will determine suitability of plant materials

Muskrat and nutria are two other mammals that can cause problems in permanent water over 3 feet deep. Their burrowing activities may place levees and water control structures at risk unless extra width is planned. Like beavers, these animals start their burrows in deeper water, so planning for a wide, shallow berm or very gradual slope will help prevent problems. If these animals become problems, they can be controlled by trapping.

(6) Use and spatial organization

Analysis and selection of wetland sites must be based on an understanding of landscape ecology. Generally, proposed wetland changes will be of greater benefit, biologically and aesthetically, if they are planned as part of the naturally occurring aquatic ecosystem. Understanding existing patterns and connections between various landscape elements is critical to achieving planned objectives (fig. 13-6). For example, animals will colonize new areas if they can move upstream and downstream under cover with relative safety. Such cover can be rapidly developed through the use of soil bioengineering revegetation techniques, which offer protection that ensures the natural function, health, and survival of fragile sites and species. Waterfowl need both open areas and cover to feed, roost, and nest, whereas some migratory songbirds need connected bands of trees and shrubs to provide movement corridors through the landscape. A restored wetland will colonize more quickly and become more productive if it is linked to existing wetlands. Where practical, restore wetland complexes that maximize biological diversity.

Wetland values are also enhanced when adjacent landscape conditions are taken into account. For example, buffers can increase wetland productivity by separating a restored or enhanced wetland from other areas of incompatible use. Adjacent riparian forests, for example, will protect fragile wetland ecosystems while improving plant diversity, cover, and food sources within parts of the ecosystem. In addition, such a forest may reduce or prevent undesirable access to the wetland, temperature gain, encroachment by farm machinery, erosion, and overland nonpoint source pollution. Soil bioengineering technology may be used to quickly reestablish natural riparian zones to serve these needs and enhance overall wetland buffer functions.

Figure 13-6 Relationship of the site to other ecological features within the landscape should guide planning

Placing wetlands on headwaters of cold water fish streams may adversely affect a fishery since it can raise the streams temperature.

(7) Recreation

Wetlands can accomodate two general categories of direct human use and recreation consumptive uses, such as hunting and fishing, and non-consumptive uses, such as educational tours and lectures, birdwatching, nature trails, boating, hiking, jogging, biking, and horseback riding (fig. 13-7). Wetlands can be designed to be used for both categories or for a single purpose.

Incorporating human recreational use into a wetland site may involve designing access roads or paths, comfort facilities, observation platforms, fishing piers, hunting blinds, and any number of other structures as part of the wetland. These structures should neither detract from the wetland nor interfere with its biological and other functions. Avoid, for example, placing trails through large homogenous ecosystems in order to preserve as much interior biotic environment as possible. Trails should be located to weave in and out of the edge of ecosystems, at the transition zone. Structures will add to the costs of the overall project, but greater use and visibility of the wetland may make this a desirable trade-off.

Technical guides for designing recreational structures and facilities are available from the Army Corps of Engineers, the Fish and Wildlife Service, and the National Park Service.

(8) Aesthetic quality and open space

Aesthetic quality is a fundamental reason for choosing leisure and recreational sites. Many people perceive wetlands in modified rural and urban environments as remnants of the natural landscape. Land management decisions, including those related to wetland restoration, enhancement, or creation, are often made because of a landowner's perception of what will beautify the land and reflect a stewardship ethic to his or her neighbors.

Landowners may be reluctant to adopt conservation practices or landscape features that contradict aesthetic norms for attractive or well-cared-for land. A landowner's willingness to cooperate in wetland restoration or enhancement activities or to manage and protect a wetland over the long term can be directly related to the planner's ability to blend the wetland with the existing landscape. Wetlands contribute significantly to scenic quality, thereby attracting tourists or others seeking recreation and providing economic development opportunities. The edge of wetlands and other places where people enter

Figure 13-7 Wetlands accommodate consumptive and non-consumptive forms of human use and recreation

Figure 13-7a Consumptive (U.S. Fish and Wildlife Service photo)

Figure 13-7b Non-consumptive

the wetland site are key opportunity areas for measures that display the landowner's intent to care for the land and include wetlands as an important part of land management.

As human populations continue to grow and require natural resources, the need for open space becomes increasingly important for both physical and psychological well-being. Wetlands provide extremely important remnants of open space in many urban settings and contribute significantly to the pattern of open space to be found in the rural landscape (fig. 13-8). In addition to open areas of water, wetland open space can take the form of vegetated riparian corridors that may connect with other corridors to provide a complex pattern of greenway open space.

(9) Cultural features

Cultural resources are associated with a variety of landscapes, including low-lying areas that may be ideal for wetland restoration, enhancement, or creation. Typically, the resources that may be encountered in this environment consist of archeological sites, earthen features, and historic structures and buildings. Any resource sites that are identified may be very important because of the unique preservation potential associated with wetland conditions.

Figure 13-8 Wetlands contribute significantly to open space found in urban and rural settings

Cultural resources need to be considered early in the planning process. Both the SCS General Manual, Title 420, Part 401, and the national cultural resources training program provide guidance for this process, as well as procedures for when cultural resources are unexpectedly discovered. Planners need to work closely with landusers, an SCS cultural resources coordinator, the State Historic Preservation Office, and Native American groups to ensure that proposed practices or installation do not harm significant cultural resources. This process is required by several Federal and state cultural resource laws. It is also part of the requirements for a Section 404 permit, if applicable.

(10) Social

Planners need to work closely with the landuser during the planning process to ensure that his or her objectives are being met. Aesthetics, recreation, wildlife habitat, social values, conservation ethics, economic considerations, or the desire to protect ground or surface water might each play a role in the decision to restore, enhance, or create a wetland.

Due to Federal, State, and local guidelines, permit - requirements, and regulations, the potential for conflict exists between landusers, planners and other agencies. It is important for planners to recognize this potential.

The SCS Social Science Manual, available through the National Sociologist, NTC sociologists, and state sociological coordinators, outlines a process people go through when adopting innovations. Some of this information would be helpful to planners as they work with landusers on land use decisions involving wetlands.

(11) Economic evaluation

Monetary values associated with wetland restoration, creation, or enhancement are difficult to determine. It is relatively easy to base economic values on the production of forage or livestock water, hunting and fishing fees, visitor days, and other accepted measurements. It is much more difficult to determine economic values of wetland functions such as ground water recharge, water quality improvements, floodflow alteration, preservation of open space, or aesthetic quality. Functional wetland benefits enjoyed by the general public can often equal or exceed those planned by the landowner.

Composite benefits to the overall landscape ecology, such as restoring fragmented habitats and connecting landscape patterns, although poorly understood, are also important.

Economic analysis can be performed with combinations of monetary and non-monetary information. Performing a strictly monetary benefit-cost analysis for wetland creation, restoration, or enhancement is difficult because much information is lacking concerning the physical effects of wetland improvements. Two broad approaches can be used to resolve this problem. The first is to perform a least-cost analysis, which essentially requires determining the least costly way to achieve a given level of wetland values. The second is more comprehensive and involves displaying, for the decisionmaker, both the monetary and non-monetary effects of each wetland improvement option. A key element in the analysis is to determine the base condition, or the benefits and costs associated with the current land use. The SCS Economics of Conservation Handbook, Part 1, should be used when conducting an economic evaluation.

(12) Environmental evaluation

During planning, an environmental evaluation may be needed to comply with the National Environmental Policy Act and many state laws. States generally have checklists of environmental concerns.

In planning, potential impacts of alternatives to environmental concerns are considered. Proposed work must avoid harming such concerns as rare, threatened, or endangered species and archaeological sites that are protected by law. It should avoid or minimize affecting other environmental concerns.

Protection of threatened or endangered species or critical habitat is especially important since many such plant and animal species are associated with wetlands. Federal and state lists are maintained by SCS, the Fish and Wildlife Service, state departments of natural resources, a state's Natural Heritage Program, or other appropriate state offices. These lists must be reviewed to verify whether species are present or that their habitats either exist or can be developed at the proposed site.

(13) Permits and regulations

It may be necessary to obtain Federal, state, or local permits prior to wetland restoration, enhancement, or creation. Where a natural wetland exists, a Section 404 permit may be necessary before construction can begin. Section 404 of the Clean Water Act (33 U.S.C. 1344) and Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403) are two of the Federal authorities for jurisdiction in wetlands of the United States. Permits are evaluated and issued by the Corps of Engineers and subject to review by EPA. In addition, Section 401 of the Clean Water Act may sometimes require a water quality certification permit for a wetland construction project.

Water rights, or the rights to adequate water supplies for certain uses, are controlled by each State and often by a local water district. On wetland sites where an adequate supply of clean water is in doubt, it is absolutely essential that this question be addressed before the wetland is planned and sited. Water rights may be obtained through outright purchase from local farmers or ranchers and in some cases through State assertion of water rights for protection and enhancement of natural resources in the public interest. In certain states, water diversion, pond construction, and/or manipulation of any water supply must be coordinated and approved by local and/or state agencies.

650.1303 Design

The wetland designer must consider a number of critical factors including hydrology, soils/geomorphology, hydraulics, structural components, and plant materials. To ensure a successful design, use an interdisciplinary approach.

(a) Data collection

(1) Surveying

Once the wetland functions and location have been determined, a sufficient number of surveys are needed so that dikes, water control structures, spillways, vegetation, and other features of the wetland can be designed (fig. 13-9).

Several items should be addressed in the planning and surveying phases of wetland restoration, creation, or enhancement. Critical elements that should be addressed but are often overlooked are:

- (*i*) Extent of flooding of lands outside of the wetland or easement area.
- (*ii*) Impact on roads, rights-of-way, utilities, or other public facilities.
- (*iii*) Effect on existing drainage, both upstream and downstream.
- (*iv*) Species of plants in adjacent wetlands and upland areas.

A topographic survey will be necessary for most wetland sites to determine water depth, surface area, management possibilities, and quantities of construction materials.

Figure 13-9 Site surveys are prerequisite to design and construction of wetlands.

Survey data for evaluation depends upon site characteristics such as steepness of slopes, size of drainage areas, and size of the impoundment. It is recommended that enough information be obtained to plot a contour map showing intervals of 1 foot or less.

Several methods are used in topographic mapping. The survey method used will depend on the type and function of the intended wetland and on the survey equipment available.

As a minimum, surveys should include the following:

(*i*) A location sketch showing property boundaries, benchmarks, permanent features, orientation, and wetland location.

(*ii*) Profiles and cross sections describing typical or critical parameters of the existing conditions. These might include:
- Channel grades
- Description of existing drainage system and elevations
- Hydraulic controls, such as bridges, culverts, and channel restrictions
- Existing ground elevations and topographic information needed for the design of structural components.

(*iii*) Location and elevation of necessary soil borings.

One or more good benchmarks must be set that will not be destroyed during construction. These benchmarks will also be used for monitoring once construction is completed. They should be tied to locally recognized benchmarks with mean sea level datum whenever possible, especially for large and perpetual projects.

These limitations and requirements should be used as guidelines in the planning and design of a wetland project. Other onsite factors which need to be considered when deciding what degree of surveying is necessary include downstream hazards, restoration requirements, and hydrologic conditions. Guidelines for surveying techniques and notekeeping can be found by referring to Engineering Field Handbook (EFH) Chapter 1, Engineering Surveys, and SCS Technical Release No. 62.

(2) Geotechnical investigation

If structural components are to be installed, the foundation investigation should include soil borings to determine if the site is suitable. When a soil survey of the area is available, it may be used as a guide to determine boring locations. When no soil survey is available for the preliminary analysis, boring locations should be based upon site features and the findings as the investigation continues.

It may be desirable to open a pit for a close study of the substrate. Borings or pits should reveal:

(*i*) The elevation of the water table

(*ii*) Position, thickness, and classification of each soil layer

(*iii*) The existence of any foreign materials, such as shell deposits

(*iv*) Soils, which should be classified and logged using the Unified Soil Classification System (table 13-2)

At the least, the borings; should be made to a depth sufficient to define the foundation conditions. The location and thickness of highly permeable soil layers should be identified to determine their influence on piping potential and seepage. Guidelines for classification techniques and log keeping can be found by referring to EFH Chapter 4, Elementary Soil Engineering.

(b) The hydrologic system

For a wetland to be functional, it must have adequate amounts of water during appropriate times of the year. Hydrologic studies of existing or potential wetland systems may be relatively simple and require only a few assumptions and estimates; however, some wetlands may be so complex that they require the services of a hydraulic engineer. An examination of the water budget, the relationship between the water budget and the hydroperiod, and the flow characteristics within a wetland are necessary to understand wetland hydrology.

Table 13-2 Soil characteristics related to dikes

Group symbol	Soil description coarse grained soils (Less than 5096 passing a #200 sieve)	Suitability for class III dikes	Permeability and slopes
GW	Well graded gravels and gravel-sand mixtures. little or no fines.	Very stable - suited for shell of dike. Good foundation bearing.	Rapid - will need core.
GP	Poorly graded gravels and gravel-sand mixtures. little or no fines.	Stable - suitable for shell of dike. Good foundation bearing	Rapid - may not need core for lower stages of short duration.
GM	Silty gravels and gravel-sand-silt mixtures.	Stable - generally adequate for all stages. Good foundation bearing. Good compaction with rubber tires.	Moderate - may not need core except for long flood duration.
GC	Clayey gravels and gravel-sand-clay mixtures.	Stable - adequate for all stages. Good foundation bearing. Good compaction with rubber tires.	Slow permeability.
SW	Well graded sands and gravelly sands. Little or no fines.	Very stable - adequate for class III dikes. Good foundation bearing. Compaction can be done with crawler tractor.	Rapid - may need core for higher stages of long duration.
SP	Poorly graded sands and gravelly sands. Little or no fines.	Stable - adequate for class III dikes. Generally fair foundation bearing. Use flat slopes and wide berm. Compaction can be done with crawler tractor.	Rapid - will need core for long duration. Use flatter slopes. Protect against wave action.
SM	Silty sands and sand-silt mixtures.	Fairly stable - adequate for low stages. Only fair foundation bearing. Use wide berm. Good compaction with rubber tires.	Moderate - use flat slope on wet side. Protect against wave action.
SC	Clayey sands and sand-clay mixtures.	Stable - adequate for all stages. Generally good for foundation bearing. Fair compaction with rubber tires.	Slow permeability.
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands and clayey silts of slight plasticity.	Low stability - generally adequate for low stages. Fair foundation bearing. Dumped fill should be used on class III only. Fair compaction with rubber tires.	Moderate - use flat slope on wet side. Protect slopes against all erosion forces.
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, and lean clays.	Stable - adequate for all stages. Fair foundation bearing. Fair compaction with rubber tires. Use dumped fill on lower stages only.	Slow permeability.
OL	Organic silts and organic clays having low plasticity.	Very low stability - may be adequate for class III dikes of low height. Can use dumped fill.	Moderate - use for very low stage only. Slopes at natural angle of repose when wet.
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils and elastic silts.	Low stability - generally adequate for all stages. Difficult to compact. Could use dumped fill for low stages. Poor foundation bearing.	Slow permeability. Use flat slopes and protect against erosion.
CH	Inorganic clays having high plasticity and fat clays.	Fairly stable - adequate for all stages. Poor compaction, dumped fill may be adequate.	Very slow permeability. Use flat slopes on wet side.
OH	Organic clays having medium to high plasticity and organic silts.	Very low stability - adequate only for low stages and can use dumped fill. Has poor foundation bearing and compaction.	Very slow - use for low stages only. Use flat slopes.
PT	Peat and other highly organic soils.	Very low stability - use only for temporary dikes. Remove from foundation for mineral soil dikes.	Variable - may vary significantly between vertical and horizontal.

(1) The water budget

The basic formula for the water budget is as follows:

$$\Delta S/\Delta t = Q_i - Q_o \qquad \text{[Eq. 13.1]}$$

where:

- $\Delta S/\Delta t$ = the change in storage volume per change in time
- Q_i = the flow rate of water entering the wetland, vol/time
- Q_o = the flow rate of water leaving the wetland, vol/time

Equation 13.1 translates into the following equations where all values are given in consistent units of units of volume per unit time unless otherwise specified For water entering a wetland the formula is:

$$Q_i = P+R_i+B_i+G_i+P_i+T_i \qquad \text{[Eq. 13.2]}$$

where:

- P = Direct precipitation on impoundment area
- R_i= Storm water runoff from contributing drainage area
- B_i = Base flow entering the wetlands
- G_i = Seepage and springs from ground water sources
- P_i = Water pumped or artificially added to the wetland
- T_i= Tidal flow in I

For water leaving a wetland the formula is:

$$Q_o = E + T + R_o + B_o + G_o + P_o + T_o \qquad \text{[Eq. 13.3]}$$

where:

- E = Evaporation from surface
- T = Transpiration from plants
- R_o = Stormwater outflow
- B_o = Base flow leaving the wetland
- G_o = Deep percolation below the root zone of the substrate
- P_o = Water pumped or artificially removed from the wetland
- T_o = Tidal flow out

For water stored in a wetland, in units of volume, the formula is:

$$S = S_S + S_P \qquad \text{[Eq. 13.4]}$$

where:

- S = Total volume of water stored in a wetland
- S_s = Volume of stored surface water
- S_p = Volume of water in the rooting zone of the substrate

Below is a description of each of the above factors and guidance for how to develop numerical values for the factors.

(***i) Precipitation (P)***—The amount of rain and other precipitation (P) which falls directly on a wetland can be determined from local precipitation data. In examining the data, it is important to look for patterns in seasonal variation, peak events, and the length of dry periods. In many areas, the climate has distinct wet and dry periods.

(ii) Storm water runoff (R_i and R_o)—Runoff can enter a wetland (R_i) through a channel system, by overland flow, or by both methods. River flooding of alluvial wetlands has a direct impact on the total volume of water entering that type of wetland. During most times of the year, the runoff volumes are directly related to precipitation events. However, in many areas, the runoff volumes during spring thaw will not be directly tied to an individual rainfall event. The storm water outflow (R_o) may be the most critical value in designing water control structures for a wetland, but it is often difficult to determine. In general, the total volume of storm water outflow will be equal to the total volume of storm water inflow unless outflow is reduced by available permanent storage. The peak flow of storm water outflow should be reduced from the peak flow of the storm water inflow by the resistance to flow within the wetland and the available temporary storage capacity. During major events, the total volume and peak flow of storm water outflow may show little change from the total volume and peak flow of storm water inflow. Runoff rates and volumes from the contributing drainage area can be determined with the help of EFH Chapter 2, Estimating Runoff.

(*iii*) Evaporation/transpiration (*E* and *T*)
Evaporation (E) is an estimate of the water released to the atmosphere from the free water surface or from the surface of the exposed substrate. Evaporation is normally estimated from pan evaporation data collected at a nearby station (NOAA records). Transpiration (T) is an estimate of the water released to the atmosphere from emergent vegetation based upon the leaf area index of the emergent vegetation. If wetlands contain large open areas with little emergent vegetation, evaporation and transpiration should be calculated separately. If wetlands are covered with vegetation, evaporation and transpiration may be calculated together as evapo-transpiration. It may be necessary to consult a water management engineer or an agronomist for estimates of the E and T.

(iv) Baseflow(B_j and B_o)—The base flow includes all sources of flow entering (B_i) or leaving (B_o) a wetland except for those associated with the ground water or storm runoff. The base flows entering or leaving wetlands can be determined directly by measuring the cross sectional area of each flow channel and multiplying that figure by their respective average velocities. Data from streams in the area will help determine the seasonal fluctuations of the base flow throughout the year. Both base flow measurements should be taken the same day during a time that the flow is not significantly affected by surface runoff.

(v) Ground water (G_i and G_o)—The seepage and spring flow (G_i) from ground water sources and the percolation (G_o) through the substrate below the root zone of a wetland may be estimated by measuring the difference in the base flow entering and leaving a wetland over a given time period. Ground water flow is usually less seasonal than surface water flow. If interaction with ground waters has a significant impact on the water budget, the services of a ground water geologist or a water management engineer may be required.

(vi) Pumped water (P_i and P_o)—The volume of water pumped into (P_i) or out (P_o) of a wetland can be determined from the use and capacity of the pump.

(vii) Tidal flows (T_i and T_o)—Tidal flows in (T_i) and out (T_o) are periodic and predictable. Tidal freshwater and saltwater marshes and mangrove swamps have one or two tidal periods per day. Tidal flow varies in bimonthly patterns. The frequency with which flooding occurs as a result of tidal flow varies with the elevation of the surface of a wetland.

(viii) Stored surface water (S_d)—The volume of stored surface water (S_d) can be determined from a stage storage curve developed from a topographic survey of the wetland.

(ix) Stored pore water (S_p) —The water storage capacity is the volume of water stored in the pores of the substrate (S_p) in the rooting zone. The unit volume of pores in the substrate can be determined by a laboratory analysis of an undisturbed substrate sample. The storage volume of the substrate can be determined by multiplying the average depth of the substrate by the surface area of the wetland and the unit volume of pores.

(2) The hydroperiod

The hydroperiod is the seasonal pattern of the water level of a wetland. An analysis of the hydroperiod will determine the availability of water throughout the year; the extreme wet and dry conditions which can be expected; the extent of storage, drainage, and pumping which may be required for the proposed function; and the design of the water control facilities in the wetland. This analysis will identify limitations on wetland function associated with the water budget and potential management alternatives. The hydroperiod of the wetland can be determined from the data gathered for the water budget.

To achieve the desired goals of the hydrologic system it may be necessary to manipulate the factors of the water budget. This may be achieved by the following methods:

- (*i*) The runoff inflow may be increased or decreased by diverting runoff water into or out of the wetland area.
- (*ii*) The rate of runoff inflow may be controlled by a water control structure upstream from the wetland.
- (*iii*) The rate and volume of runoff may be altered by changes in the land use and management of the contributing drainage area of the wetland.

(*iv*) The base flow into the wetland may be reduced by diverting it around the wetland.
(*v*) The evapo-transpiration rate may be controlled by selection and management of vegetation and by windbreaks surrounding the wetland.
(*vi*) The volume of water pumped into or out of a wetland can be varied.
(*vii*) The volume of storage in a wetland can be altered by the construction of levees and water control structures.
(*viii*) Excavation of deep pools or fill can increase or decrease water storage capacity. Deep pools may be desirable to provide variation of habitat and pockets of surface water during dry periods.

(3) Flow characteristics of wetland systems

The flow characteristics of a wetland describe the movement of water with the wetland system. Understanding and predicting the internal flow characteristics can be critical to the restoration, enhancement, or creation of a wetland for a specific function. The three basic flow systems found in wetlands are depressional, riverine, and tidal (fig. 13-10). The flow characteristics of a given wetland may exhibit qualities of each. Wetland flow characteristics also include both surface and subsurface flow. Wetlands with spatially variable conditions may be analyzed by:

1. Dividing the wetland into segments of similar characteristics.
2. Writing a mass balance equation for each segment.
3. Solving the simultaneous equations for the unknowns.

(i) Depressional systems—The principal physical features of depressional systems are length, depth, drainage area, surface area, and volume. The relationships between volume, depth, and surface area can be shown on a stage storage curve. They have relatively low flow-through velocities and long retention times. Deep areas in these systems develop temperature gradients; however, in shallow wetlands these temperature gradients may be insignificant. Mixing occurs by wind action at the surface, currents generated from inflow, and by movements resulting from temperature gradients. Evaporation is often a critical factor in the water budget.

Retention time is the ratio of the volume of the system and the flow leaving the system.

$$t_r = V/Q \qquad \text{[Eq. 13.5]}$$

where:
t_r = retention time, days
v = volume of water in the system, ft^3 (m^3)
Q = flow leaving the system, ft^3/day (m^3 /day)

The inverse of the retention time is sometimes called the turnover rate.

The overflow rate can be expressed as a ratio of the flow leaving the system and the surface area or as the ratio between the average depth and the retention time.

$$q = Q/A = H/tr \qquad \text{[Eq. 13.6]}$$

where:
q = overflow rate, ft/day (m/day)
Q = flow leaving the system, ft^3/day (m^3/day)
A = surface area of the wetland, ft^2 (m^2)
H = average depth, ft (m)
t_r = retention time, days

(ii) Riverine systems—The principal physical features of riverine systems are width, depth, length, crosssectional area, resistance to flow, hydraulic gradient, velocity of flow, and volume of flow. Small streams are often characterized by alternating pools and rifts. The characteristics often vary along with the length of the system, and if the variations are significant, the system can be analyzed in reaches. The flow may vary seasonally, and the limiting factors to the design and utilization of these systems should be analyzed for both low flow and high flow conditions.

Volume of flow in riverine systems is the product of the velocity and the cross sectional area, as expressed by the continuity equation.

$$Q = AV \qquad \text{[Eq. 13.7]}$$

where:
Q = volumetric flow rate, cfs (m^3 /sec)
A = cross sectional area, ft^2 (m^2)
V = mean velocity, ft/sec (m/sec)

Figure 13-10 Basic flow systems found in wetlands

Figure 13-10a Depressional (U.S. Fish and Wildlife Service photo)

Figure 13-10b Riverin

Figure 13-10c Tidal

Velocity varies with width, depth, and resistance to flow. The velocity measured at 0.6 of the depth from the surface will approximate the mean velocity. The relationship between the mean velocity and the geometry of the system, the resistance to flow, and the hydraulic gradient across the system is expressed by Manning's equation.

$$V = (C/n)(r^{2/3})(s^{1/2}) \qquad \text{[Eq. 13.8]}$$

where:
- V = mean velocity, ft/sec (m/sec)
- n = channel roughness coefficient,
- r = hydraulic radius, ft (m)
- s = hydraulic gradient which may be approximated by the average slope of the channel bed, ft/ft (m/m)
- C = 1.486 for English units and 1.0 for SI units.

The hydraulic radius used in Manning's equation is the ratio of the cross sectional area of the flow and the wetted perimeter.

$$r = A/P \qquad \text{[Eq. 13.9]}$$

where:
- r = hydraulic radius, ft (m)
- A = cross sectional area of the flow, ft^2 (m^2)
- P = wetted perimeter, ft (m)

Streams in wetlands tend to have higher Manning's *n* values than upland streams. Typical Manning's *n* values for streams in a wetland with flow depths greater than 1 foot are given in table 13-3 as a guide.

N values for flow depths between 3 inches and 1 foot may be determined using figure 13-11. The formula for the retardance curve index number is:

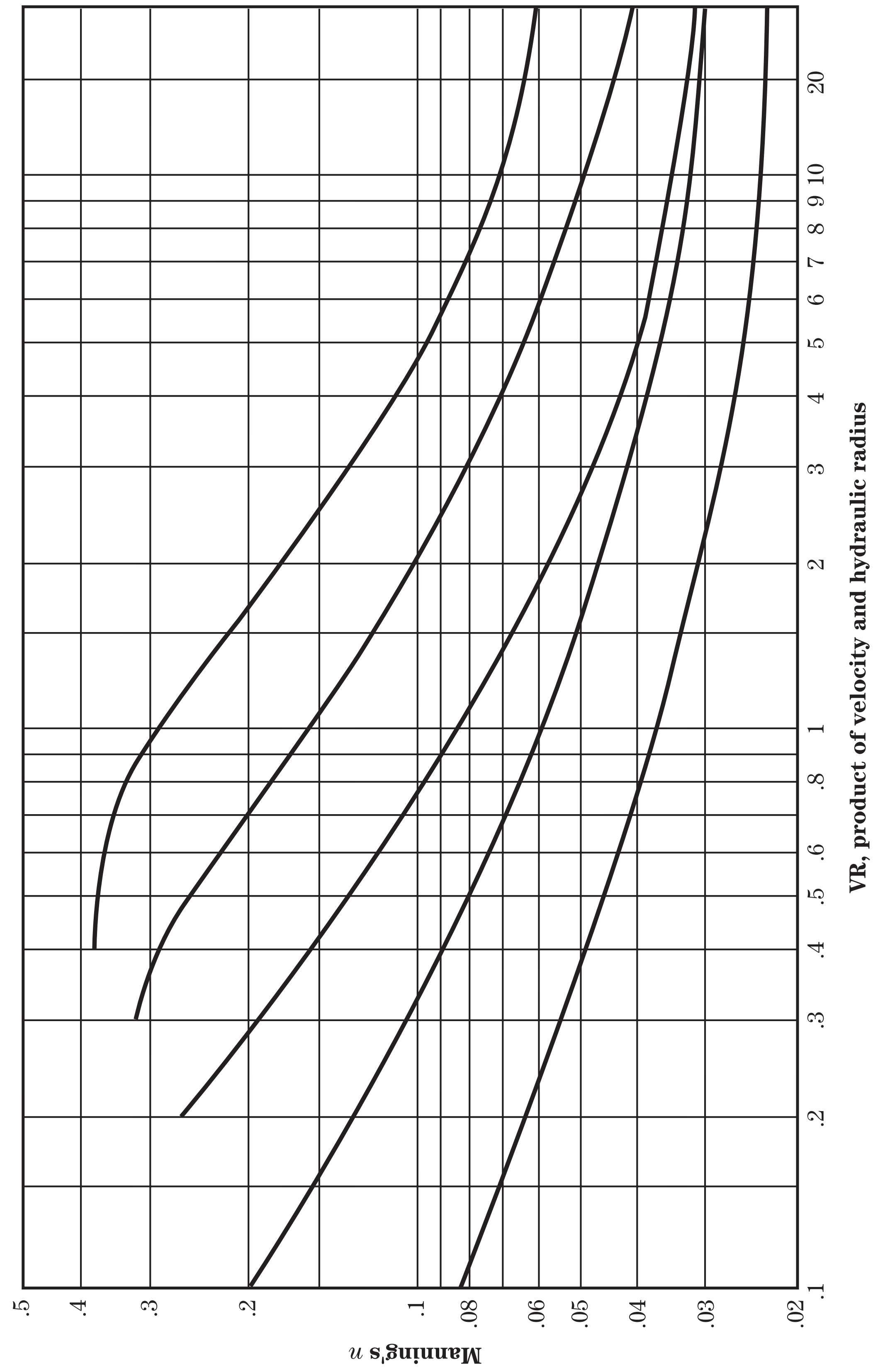
$$CI = 2.5\,(h(M)^{1/2})^{1/3} \qquad \text{[Eq. 13.10]}$$

where:
- CI = retardance curve index number
- h = representative stem length in feet
- M = average stem density in stems ft^2

Table 13-3 Manning's *n* values for wetland streams with flow depths greater than 1 foot

Stream conditions	Manning's n
1. Clean straight banks, full stage, no rifts or deep pools	0.035 - 0.040
2. Same as 1, but more weeds or stones	0.040 - 0.045
3. Winding, some pools and shoals, clean	0.045 - 0.055
4. Same as 3, lower stage, flatter slopes	0.050 - 0.060
5. Same as 3, some weeds or stones	0.045 - 0.065
6. Same as 4, stony sections	0.055 - 0.070
7. Sluggish sections, rather weedy, very deep pools	0.060 - 0.085
8. Very weedy reaches	0.075 - 0.150

Figure 13–11 Manning's "n" related to velocity, hydraulic radius, and SCS retardance class curve



The relationship between the retardance curve index number and SCS retardance class curves is given in table 13-4.

Table 13-4 Retardance curve index vs. SCS class

Retardance curve index number	SCS retardance class curve
10.00	A
7.64	B
5.60	C
4.44	D
2.88	E

For flow depths less than 3 inches in dense vegetation, Manning's equation may no longer apply. The flow could be analyzed as flow through a porous medium using Darcy's law as described under subsurface flow.

(iii) Tidal systems—The principal features of tidal systems are the cyclic movement of water into and out of the system as a result of the tides, the net flow out of the system resulting from the freshwater inputs, and the incursion of salinity from the ocean. Freshwater is usually less dense than the saline water from the oceans, so stratification occurs, with the freshwater at the surface and the saline water at the bottom.

Tidal stage can be measured directly or estimated from local records. Tidal flow is characterized by a cyclic sinusoidal variation between ebb and flood. Net freshwater flow is a function of the volumetric flow and duration of the ebb and flood flow.

$$Q_n = 2(Q_e T_e - Q_f T_f) / (T_e + T_f) \qquad \text{[Eq. 13.11]}$$

where:

Q_n = net freshwater flow, ft^3/day (m^3/day)
Q_e = maximum ebb tidal flow, ft^3/day (m^3 /day)
Q_f = maximum flood tidal flow, ft^3/day (m^3/day)
T_e = duration of the ebb flow, days
T_f = duration of the flood flow, days

(iv) Subsurface flow—Subsurface flow, either into or out of a wetland system, is often an important element of the wetland system. Darcy's law is the formula used to describe flow through a porous medium.

$$Q_g = Kia \qquad \text{[Eq. 13.12]}$$

where:

Q_g = subsurface flow, cfs sec (m^3/sec)
K = saturated hydraulic conductivity, ft/sec (m/sec)
i = hydraulic gradient ft/ft (m/m)
a = cross sectional area ft^2 (m^2)

Typical values for the hydraulic conductivity for various soil types are given in table 13-5.

Table 13-5 Hydraulic conductivity vs. soil texture

Soil type	English units: Min. K, ft./sec	Max. K, ft./sec
Clays	< 3.3 x 10-8	
Peat	3.3 x 10-8	3.3 x 10-7
Silt	3.3 x 10-7	3.3 x 10-6
Loam	3.3 x 10-7	3.3 x 10-5
Very fine sands	3.3 x 10-6	3.3 x 10-5
Fine sands	3.3 x 10-5	3.3 x 10-4
Coarse sands	3.3 x 10-4	3.3 x 10-3
Sand with gravel	3.3 x 10-3	3.3 x 10-2
Gravels	> 3.3 x 10-2	

To obtain SI units (m/sec) divide by 3.3.

(c) Structural components

(1) Dikes and levees

Both dikes and levees will be referred to as dikes in this discussion. Dikes are embankments of earth or other suitable materials constructed to contain water or protect lands against overflows from lakes, streams, and tides. Dikes will often be an integral component of wetland restoration, enhancement, or creation.

The following guidelines and procedures apply generally to dikes constructed in rural or agricultural areas where minimum damage is likely to occur from dike failure, and the maximum design water stage against the dike is 6 feet (1.8 m) for mineral soils and 4 feet (1.2 m) for organic soils. Channels, sloughs, swales, and gullies should be excluded in determining the design water stage.

Causes of dike failure are overtopping, undermining, sloughing, piping, or seepage along water control structures placed through the dike. The design of the dike should eliminate these dangers as much as possible. Since dikes usually are long, and differences in soil conditions normally exist along the route, adjustments may be needed in the design section and construction methods for the different soil conditions.

Locating the dike away from a channel so that it will not be scoured by high velocities will protect against undercutting. The potential sloughing of the dike can slopes and construction methods. Piping and erosion potential along conduits should be controlled by using a filter and drainage diaphragm or anti-seep collars. The drainage diaphragm should be located about 2/3 of the distance from the inlet to the outlet. Anti-seep collars are designed to increase the seepage length by 15 percent along the conduit. When pumps are installed, the pump discharge pipe should be located over the top of the dike. If it is placed through the dike, the pipe should be placed above the design water surface, and the connection between it and the pump should be made with a flexible coupling to reduce vibration. Consideration should be given to the installation of an anti-siphon device.

In the design of fills, consideration should be given to the moisture conditions of the fill and foundation soils at the time the fill is placed and to the method of construction. Ideally, stable fills are constructed of moist soil placed in layers 8 to 12 inches (20 - 30 cm) thick and traversed with the hauling equipment or otherwise compacted with a roller or other compacting equipment. Plastic soils, if placed dry, will not compact and will become very soft and weak when they become wet. Any soil that is placed wet or near saturation will be very difficult to work with because it will not support equipment and may slough or slump excessively. Organic soil should be avoided in dike constructions due to excessive settlement, shrinkage, and sloughing. If organic soil must be used, it is best to construct the dike in stages where a lift is placed and allowed to settle for some time before another lift is placed over it.

Where design water stages are of long duration and heavy waves are expected, or where rapid lowering of the stage is possible, flatter side slopes and special protection for the waterside of the dike may be required. This special protection is important where the fill is of slightly plastic or non-cohesive soils.

(i) Height—The first step after the tentative dike location has been made is to determine the dike height, based on frequency of the design storm and the duration of floodwater or storm tide stages.

High stages along coastal areas result when high daily tides are increased by high winds and waves. High wind tides can be expected several times annually in some areas. Hurricane winds along the Atlantic and Gulf Coasts sometimes cause high water stages along the shorelines of freshwater lakes and reservoirs in the region. These also should be considered in design.

Records of flood stages and dates generally are available from the Army Corps of Engineers, Coast Guard Stations, municipal and port authorities, and the Coast and Geodetic Survey of the U.S. Department of Commerce. The latter issues annual editions of “Tide Tables - East Coast” and “Tide Tables - West Coast.” Localized information may be obtained from landowners, recreational groups, or other sources. Storm tides resulting from hurricanes can, in the absence of records, be assumed to last about 75 hours along the southern and eastern coasts. However, actual records should be used where available.

Flood data on large streams can be obtained from the U.S. Geological Survey, other Federal agencies, and certain state agencies. Data on small streams may be available from local community records, newspapers, and landowners. Data from landowners usually is in the form of high-water marks.

Where information on flood stages of streams is not available, an estimate of the flood stage can be made using flood routing procedures. A simple flood routing procedure is given below:

- Estimate the peak discharge for the desired storm.
- Estimate the velocity of the stream at peak discharge using Manning's equation (Eq. 13-8).
- Use the continuity equation (Eq. 13-7) to determine the required cross sectional area for the flood flow.
- Select the flood stage elevation from a stage area curve.

Where dikes restrict flow in a floodplain, it is especially important to determine the stage for the design discharge. If the floodplain on one side of a stream is to be protected by a dike, it will be necessary to find out if inundation of the unprotected land will increase in depth, duration, and extent.

The design height of the dike (H_d) will be the sum of the design high water stage (H_w), the added height (H) for wave action, if any, and the freeboard (H_f) (see fig. 13-12). The constructed height will include an allowance for settlement (H_s), which will depend on the foundation and material used in construction. The actual design high water stage should be based on the water surface profile.

Freeboard (H_f) the allowance added to the selected flood stage without the inclusion of wave heights. Minimum freeboard shall be as given in table 13-6.

Wave height allowances (H_v) should be based on the best local experiences or computed by an acceptable formula. Table 13-7 may be used for open water reaches of less than 2,000 feet The Stephenson formula with the Gaillard modification may be used in computing wave heights for open water reaches not to exceed 10 nautical miles, and for winds not to exceed 60 miles per hour.

The basic Stephenson formula is as follows:

Wave height,

$$H_v = (1.5\ f^{1/2}) + (2.5 - f^{1/4}) \qquad \text{[Eq. 13.13]}$$

where:

H_v = Wave height, trough to crest, ft
f = Fetch, open water, in miles

Formula here To convert H_v to a wave height above high water stage, Gaillard suggests that it be modified as follows:

$$\text{Modified wave height (ft)} = H_v\ 0.75 \qquad \text{[Eq. 13.14]}$$

It is recommended that where waves are expected to have appreciable velocity, resulting in a run up the dike, the Stephenson formula should be used to provide a reasonable degree of safety.

Vegetative growth between the dike and open water, if sufficiently high and dense, will tend to reduce wave heights. In such instances, allowances in (H_v) can be made. Such allowances should be based on plant growth and permanence of the stand and condition.

Figure 13-12 Section through dike

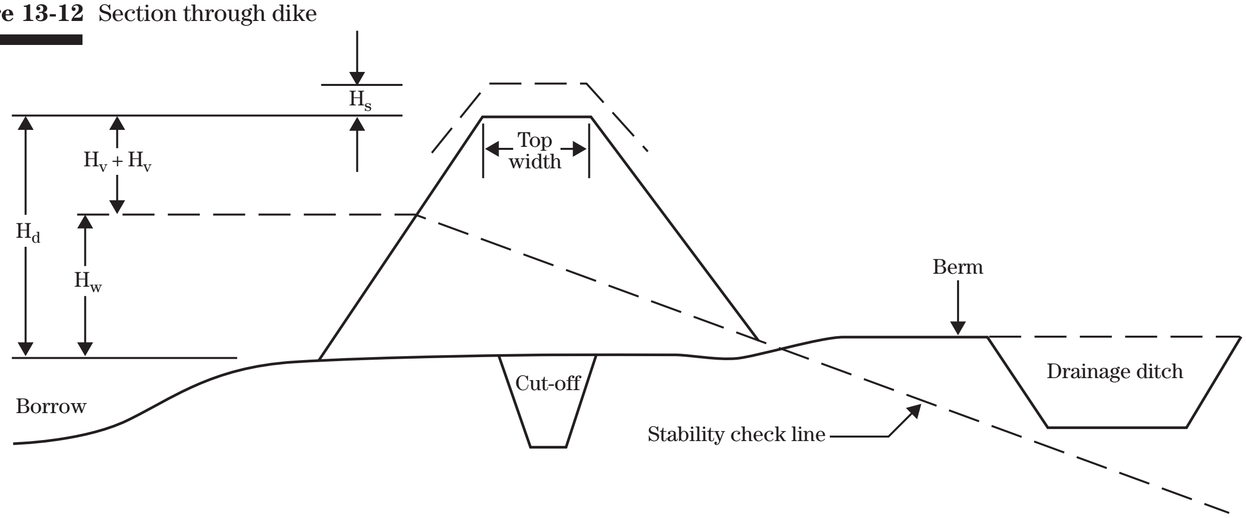


Table 13-6 Dike design recommendations

Design water height (ft) (H_w)	Minimum top width (ft)	Minimum design side slope	Minimum freeboard[1/] (ft) (Hf)	Minimum berm[2/] (ft)
Mineral Soils				
0-1	0	3:1	0.4	0
1-3	4	2.5:1	0.8	4
3-6	6	2:1	1.0	6
Organic Soils				
0-2	4	3:1	0.8	10
2-4	6	3:1	1.0	15

1/ Where there is no contributing drainage area outside the impoundment, the freeboard shall be added to the normal water surface elevation in the impoundment when it is flooded.

Where there is contributing drainage area outside the impoundment, the freeboard shall be added to the water surface elevation of the emergency spillway when it is flowing at design depth. If the dike is used to protect agricultural land from flooding the minimum freeboard shall be 1 foot.

2/ A berm is not required for dikes constructed on mineral soil with bulldozers or motor graders if the slope of the adjacent borrow and the slope of the dike is 3:1 or flatter.

Table 13-7 Freeboard for wave action

Fetch (ft)	Wave height, H_v (ft)
1001-1250	0.2
1251-1500	0.4
1501-1750	0.6
1751-2000	0.8

(ii) Settlement allowance (H_s)—Settlement allowances (H_s) depend on the soil materials in the fill and foundation and on the method of construction. The moisture content of the soil during construction also is important. Where the dike is to be compacted by construction equipment operating over the area, a settlement allowance of not less than 5 percent of the fill heights should be included. Where fill is dumped and shaped, an allowance of not less than 10 percent of the height of the dike is suggested. When a dragline is used in constructing the dike, an allowance of at least 20 percent of the height of the fill is recommended. Actual allowances will be governed by the kind of soil material to be used and the moisture content anticipated. For soils exceptionally high in organic matter, the settlement allowance should be no less than 40 percent since they are likely to be placed at near-saturated condition. If mineral soil is available, place it 6 to 12 inches over the organic soil to reduce oxidation or potential burning of the organic soil.

(iii) Dike materials—Dikes usually are constructed of fill material borrowed from areas parallel to the line of the dike or from the planned wetland basin. In cases where borrow will parallel the dike location, investigations for foundation and borrow can be combined. It may be necessary to use borrow pits outside the immediate area and transport fill material to the site. If unstable soil conditions are found, it may be more economical to change the dike location rather than employ the costly construction methods required by the use of unstable soils.

For preliminary investigations, table 13-2 will assist in evaluating soil conditions along the line of the dike and can be used as a guide to soil stability and permeability.

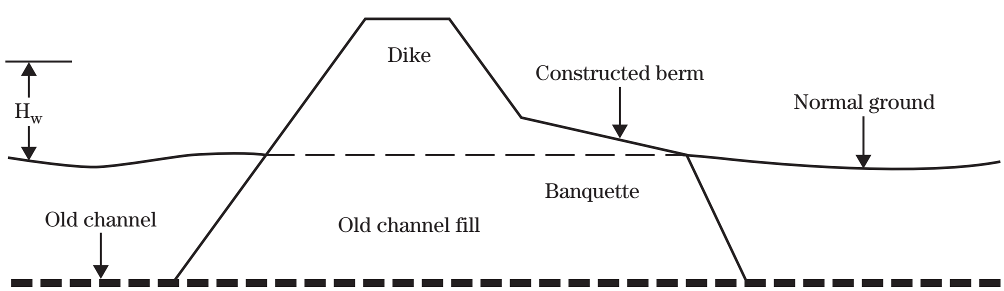
Simple field tests can be used to classify the soil according to the procedures outlined in EFH Chapter 4, Elementary Soils Engineering. This information along with a knowledge of engineering behavior characteristics may provide enough information to design stable low dikes in most average soil conditions.

(iv) Cutoff trench—When the dike foundation has layers of permeable soil or layers creating a piping hazard, a foundation cutoff or core trench should be installed. The cutoff trench should be deep enough to extend into a relatively impervious layer or to provide piping stability when combined with drainage or other seepage control. The bottom width should be adequate to accommodate equipment for excavating, and for placing and compacting the fill. The side slopes should be 1.5 to 1 or flatter. Backfill the trench with relatively impervious material or soil that has low permeability.

(v) Dike stability—Unprotected subsurface drains are not normally permitted to be closer to the landside toe of the dike than a distance equal to 3 times the design water height. If subsurface drains are to be installed or to remain closer than this distance, they should be enclosed in a designed filter, as a toe drain. Non-perforated pipe within the specified distances from the dike may be laid instead of a drain and filter.

Where a dike crosses an old channel, the base of the dike should be widened on the landside. The additional width should be at least equal to the height of the dike above normal ground elevation. The top of the extended base should be no less than 1 foot above normal ground and should slope away from the dike to provide for the runoff from the dike. The side slope of the extended fill should be no steeper than the landside slope of the dike. Such an extension of the base of a dike is known in certain areas as a banquette (fig. 13-13).

Figure 13-13 Use of a banquette at a channel crossing



The use of highly permeable soil in the dike should be avoided when possible because of potential leakage and piping. Where highly permeable soil is used in the dike fill, especially over a more slowly permeable foundation, the landside base of the dike may need to be extended, or a toe drain provided to increase the dike's stability. The phreatic line should be contained within the embankirnent cross section. The additional width or drainage may be provided in the manner shown in figure 13-14.

Where existing foundation materials are inadequate to support the dike, a geotextile material may be used to replace or reinforce portions of the foundation. This may be an alternative to removing existing material and re-compacting or replacing it with borrowed material. Geotextiles consist of either two-dimensional grids or three-dimensional webs. They are made of many types of materials and by many different manufacturers.

Berms—If borrow (borrow ditch or channel) is excavated parallel to the line of the dike, the berm which separates the dike from the borrow should be wide enough to protect the toe of the dike effectively. When the foundation materials are non-cohesive or highly permeable, the width of the landside berm should be increased to prevent piping along the face of the interior channel. Such piping along the channel could cause the berm to erode and slump, thereby undermining the dike.

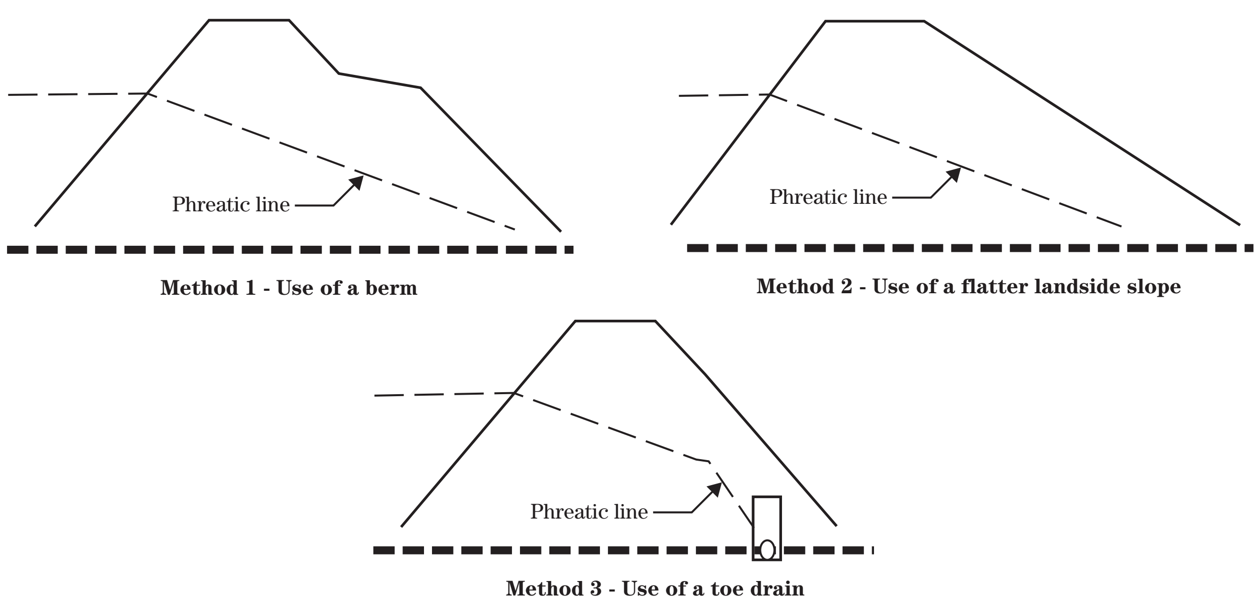
For dikes where the design water depth is more than 6 foot for short sections, the landside ditch borrow pit should be far enough away from the dike to insure stability. A line drawn from the design waterline on the face of the dike through the landside toe of the dike should, when extended, pass below the ditch or borrow pit cross section (fig. 13–12).

If a dike has a narrow top width, the landside berm should be wide enough to accommodate a maintenance roadway during critical high water periods. This facilitates travel to all sections.

Some fibrous organic soils have a steep natural slump that cannot be shaped to the planned side slopes. In such cases, the dike should be built to the designed base width and the top widened to meet the steeper side slopes. The sides will slump to flatter slopes as fibrous material decays.

The minimum dimensions recommended for dikes are given in table 13-6.

Figure 13-14 Methods of increasing the stability of a dike



Additional freeboard shall be provided to contain waves for dikes having longer surface exposure (fetch) by adding the following amounts to the applicable freeboard given above.

For fetches over 2,000 feet, use the modified Stephenson formula for total freeboard ($H_v + H_d$). In areas where dikes will be exposed to wave action for extended periods of time, additional slope protection or a berm at the water level may be required.

(2) Water control structures

Water control structures are often necessary to control and manage inflow, outflow, and drainage from a wetland.

Diversions, spring developments, or pump systems may be used to supplement inflow. Refer to EFH Chapter 9, Diversions, for discussion of design of diversions, and to Chapters 12, Springs, and 14, Drainage, for discussion of pumping system design.

Controlling the outflow from a wetland may involve capacity to store and release storm runoff, regulate pool elevation, and possibly allow for total drawdown of the wetland for management purposes. For impoundments with dikes 1 foot or less in settled height, vegetated spillways may be used in lieu of structures, and dewatering may be done by cutting the dikes. For impoundments with dikes more than 1 foot in settled height, the types of structures which may be used include:

- A straight drop structure which may be equipped with removable stoplogs, constructed of treated timber, metal, sheet piling, rock, or concrete (blocks or poured).
- A pipe provided with a swivel elbow and riser.
- A pipe drop inlet structure which may be equipped with a gate, valve, or plug for controlling flow (fig. 13–15).
- A pipe provided with a perforated riser.

Refer to EFH Chapter 6, Structures, for additional information on structure types.

Wetlands that are hydrologically isolated or that do not have a contributing drainage area will require control structures to release only the water that results from ground water inflow and precipitation. These structures should automatically draw down the temporarily stored water to the planned surface elevation in the impoundment in the desired amount of time.

Wetlands that have a contributing drainage area will require hydrologic analysis to establish peak rates and volume of runoff for the specified design frequency storm, volume of water storage required for operation and available for temporary storage, capacity of outlet channels, and limiting elevations. These data will be needed to determine the size and extent of the water control structure. Refer to EFH Chapters 2, 3, 6, and 11.

(i) Hydraulic characteristics of structures—Specific flow characteristics of water control structures depend on the type of structure planned. These flow characteristics can be generally grouped into weir, orifice, and pipe flow, where each is governed by a different set of equations, coefficients, and variables. Refer to EFH Chapter 3, Hydraulics, for additional discussion.

Weir Flow—Weir flow is a function of the effective weir length and depth of flow over the weir.

$$Q = 3.1 L_w H^{3/2} \qquad \text{[Eq. 13.15]}$$

where:
- Q = the capacity of the weir, cfs sec (m^3/sec)
- L_w = the length of the weir, ft (m)
- H = the depth of flow over the weir, ft (m)

Figure 13-15 Pipe drop inlet structure

This type of flow condition commonly occurs in drop spillway structures and drop inlets with stoplogs. Refer to table 13-8.

Orifice flow—Orifice flow is a function of the cross sectional area of the orifice opening and hydraulic head over the center of the orifice.

$$Q = 0.6A(2gH)^{1/2} \quad \text{[Eq. 13.161}$$

where:
- Q = the orifice capacity, cfs sec (m^3/sec)
- A = the area of the orifice opening, ft^2 (m^2)
- g = 32.2 feet/second per second, (9.8 m/s^2)
- H = the hydraulic head over the center of the orifice, ft (m)

This type of flow condition commonly occurs in pipes with perforated risers and pipe drop inlets. Refer to table 13-9.

Full pipe flow—Full pipe flow is a function of the hydraulic head, pipe length, pipe friction loss coefficient, and the cross sectional area of the pipe.

$$Q = A\left(\frac{2gH}{1.1 + K_e + K_P L}\right)^{\frac{1}{2}} \quad \text{[Eq. 13–17]}$$

where:
- Q = the pipe capacity in cfs sec (m^3/sec)
- A = the cross sectional area of the pipe, ft^2 (m^2)
- H = the hydraulic head, ft (in)
- g = 32.2 feet/second per second, (9.8 m/s^2)
- K_p = the friction loss coefficient
- K_e = the entrance loss coefficient
- L = the length of pipe, ft (m)

This type of flow condition commonly occurs in pipe structures.

Culverts feature a combination of the above flow conditions. There are two major types of culvert flow flow with inlet control and flow with outlet control. For each type, different factors and formulas are used to compute the hydraulic capacity of the culvert. Under inlet control, the diameter of the culvert barrel, the inlet shape, and the amount of headwater or ponding at the entrance must be considered. Outlet control involves the additional consideration of the elevation of the tailwater in the outlet channel and the

Table 13-8 Weir capacity in cfs for varying flow depths (H) and weir lengths (LW)

H, (ft)	L_w, feet 0.5	1.0	1.5	2.0	2.5	3.0	4.0
	cfs						
0.2	0.1	0.3	0.4	0.6	0.7	0.8	1.1
0.4	0.4	0.8	1.2	1.6	2.0	2.4	3.1
0.6	0.7	1.4	2.2	2.9	3.6	4.3	5.8
0.8	0.8	1.6	2.4	3.2	4.0	4.8	6.3
1.0	1.6	3.1	4.6	6.2	7.8	9.3	12.4
1.2	2.0	4.1	6.1	8.2	10.2	12.2	16.3
1.4	2.6	5.1	7.7	10.3	12.8	15.4	20.5
I .6	3.1	6.3	9.4	12.5	15.7	18.8	25.1

Note: multiply table values in cfs by 0.0283 to convert to m^3/sec.

length of the culvert. Refer to EFH Chapter 3, Hydraulics, or another hydraulics text for K_p and K_e values.

(ii) Emergency spillways—Where there is a contributing drainage area to the impoundment, emergency spillway capacity should be sufficient to carry the maximum outflow expected for the design storm. Reduction of spillway size due to temporary retention may be considered. An emergency spillway is not required where the impoundment is entirely surrounded by a dike and has no contributing surface runoff.

The emergency spillway may consist of a concrete or vegetated earthen spillway, a conduit (pipe), or a combination of a concrete or vegetated earthen and a conduit.

When the emergency spillway consists of a vegetated earthen spillway:

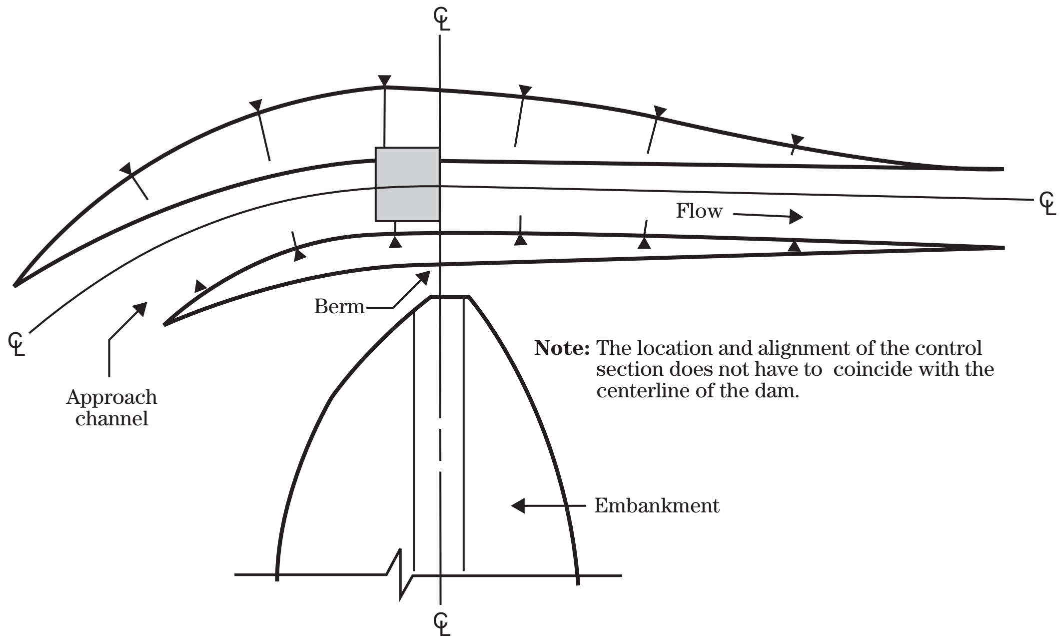
- Locate spillway in natural, undisturbed soils if possible. Choose an area at the end of the embankment where the natural terrain approaches the fill level. If necessary, cut the depth of spillway in undisturbed ground.
- The side slopes should be 3:1 or flatter.
- The minimum slope of the inlet channel should be 2 percent. The minimum slope of the exit channel should be 1 percent and the maximum slope 12 percent. Make sure the exit channel slope remains as consistent as possible throughout the length of the channel. Extend the emergency spillway channel down to a stable outlet. The alignment of the outlet section should be straight throughout its length, if possible.
- The control section should be as flat and uniform as possible across its entire width and length to reduce variation in depth of flow and potential of erosion. A minimum length of level section upstream from the control section of 25 feet is needed (fig. 13-16.)
- Elevation of the emergency spillway control section is the spillway crest or elevation at which the first flow of water flows through the emergency spillway. For sites with water control structures, the emergency spillway crest should be set at an elevation above normal water level dictated by the amount of temporary storage required for the intended function (recommended minimum of 0.5 ft).

Table 13-9 Orifice capacity in cfs for varying hydraulic head (H) and orifice area (A)

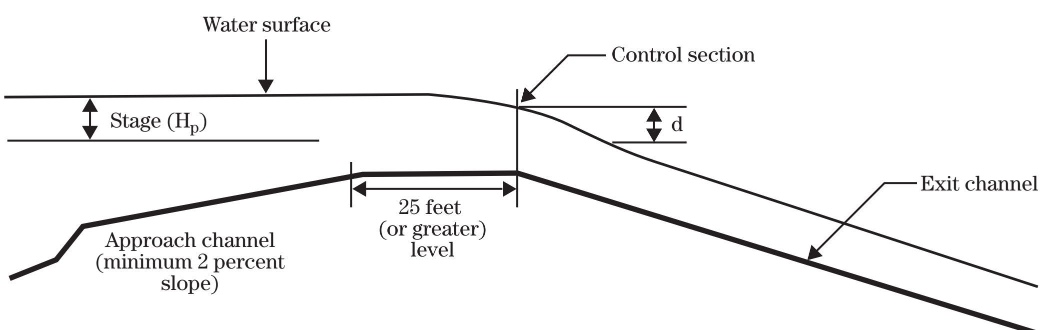
H,	A square feet						
(ft)	0.5	1.0	1.5	2.0	3.0	4.0	5.0
	cfs						
0.2	1.1	2.2	3.2	4.3	6.5	8.6	10.8
0.5	1.7	3.4	5.1	6.8	10.2	13.6	17.0
1.0	2.4	4.8	7.2	9.6	14.4	19.2	24.1
1.5	2.9	5.9	8.8	11.8	17.7	23.6	29.5
2.0	3.4	6.8	10.2	13.6	20.4	27.2	34.0
2.5	3.8	7.6	11.4	15.2	22.8	30.4	38.1
3.0	4.2	8.3	12.5	16.7	25.0	33.4	41.7

Note: Multiply table values in cfs by 0.0283 to convert to m^3/s.

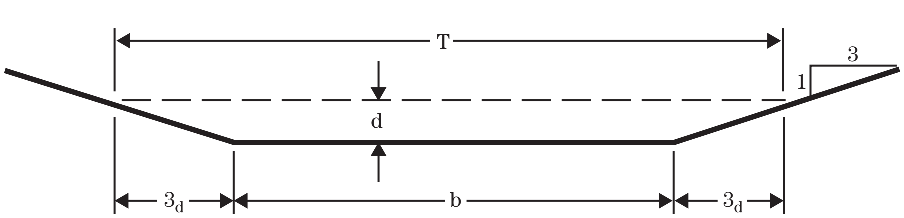
Figure 13-16 Profile and cross-section of excavated earth spillway



Plan view of excavated earth spillway



Profile along centerline



Cross-section at control section

- The crest of the emergency spillway should be at least 0.5 foot above the normal reservoir water elevation maintained by the water control structure.
- The design bottom width of an emergency spillway is determined from the required discharge capacity from the design storm. The minimum design storm should be a 10-yr frequency, 24-hr duration storm. A larger storm may be desired in many situations.

For additional discussion and design information on vegetated earthen emergency spillways refer to EFH Chapter 11, Ponds and Reservoirs.

(3) Drainage

(i) Design of drainage blocks—Surface and subsurface drains must be blocked or controlled when necessary to restore, enhance, or create wetlands (fig. 13-17). Individual subsurface drain lines must be broken and all surface inlets removed. The broken subsurface drain must be blocked or fitted with a water control structure.

The length of the subsurface drain broken and removed should be sufficient to avoid any drainage influence from the old drain. This length will vary depending upon site conditions. The minimum length of drain removed should range from 50 feet in heavy clay soils to 150 feet in sandy or organic soils.

When a dike is to be a component of the wetland, remove the subsurface drain from the centerline of the dike to the above minimum length downstream from the centerline, and from the centerline of the dike to the upstream toe. None of the old drain should be left under the dike.

If a water control structure is to be installed in the drain line, locate the subsurface drain break in the basin area, and locate the control structure at the edge of the basin. The outlet conduit for the control structure should be water tight for the above minimum lengths and should have adequate crush strength to support the load of the dike, if a dike is to be installed. The ends of the broken subsurface drain lines must be capped or controlled to prevent soil from entering the remaining subsurface drain. The following methods may be used:

- Capping the ends with an external cap that is securely cemented or grouted.
- Plugging the subsurface drain at each end with an impervious material, such as cement, that will be held securely in the subsurface drain. When subsurface drain lines also function as outlets from other drained areas where drainage is still desired, appropriate measures must be incorporated to keep the upstream drainage systems functional. These measures include installing non-perforated conduit through the wetland basin; re-routing drainage lines around the basin at a distance where t e drainage effect on the basin is negligible; or, where topography permits, setting a water control structure at a level that does not affect upstream drainage.

Where subsurface drains are blocked or removed consideration must be given to the effect of the action on remaining upstream and downstream drainage

Figure 13-17 PVC riser being installed at broken tile will raise water level.

systems.

Plans to install a section of impervious conduit through the wetland basin should follow these guidelines:

- Extend non-perforated conduit to a minimum of 50 feet upstream and downstream from the designed basin edge in clay soils and 150 feet beyond the basin edge in both directions in sandy or organic soils.
- Install an anti-seep collar around the non-perforated conduit approximately 2 to 4 feet from the connection to existing subsurface drain at both upstream and downstream ends of the conduit. The anti-seep collar should have a minimum projection of 18 in. beyond the conduit perimeter.

Under no conditions should a conduit be installed that will have less capacity than the one it is replacing.

(ii) Design of basin drainage—A wetland function may require that a basin be drained for management purposes. For example, if the wetland function is primarily food production, such as rice, it may be necessary to drain both surface and subsurface water from the basin for harvesting. This drainage may be done by a collection ditch at one end of the basin and grading of the bottom of the basin; a system of main and lateral ditches; or subsurface drain and a water control structure. Another example of a condition that could require basin drainage would be invasion of undesirable species. Eradication may require drainage of the basin.

A water control structure should be designed to provide the depth and capacity necessary for drainage as well. as other flow (storm or seepage). Refer to table 13-10.

For additional discussion and information on drainage practices and design, refer to EFH Chapter 14, Drainage.

(4) Ancillary structures

An array of installed practices or structures should be considered to serve the functions that are being planned and designed. Care must be taken to avoid or minimize adverse impacts upon other functions that may be planned. Observation platforms, for example, can be located near defined loafing habitat or feeding areas rather than nesting or brood rearing habitat where human disturbance should be kept to a minimum. The potential combinations are too numerous to address in this chapter, however, a few structures are

Table 13-10 Recommended removal rates for basin drainage

	Management function	Minimum removal rate (average) inches per day
Surface water	Food production	1.0-1.5
	Wetland plants	0.5
Sub-surface water	0.1-0.4	

cited here as examples. Design specifics for these and other ancillary structures can be found in publications listed in the references to this chapter, the Field Office Technical Guide, or by contacting the responsible discipline specialist.

Temporary or permanent fencing will often be necessary to control use of the completed wetland or allow vegetation to become established.

Upland islands can be created to provide nesting, roosting, and loafing habitat for both wetland wildlife and upland species that might not occur on the site otherwise (fig. 13-18). Excessive height and steepness should be avoided to prevent limited use and difficulty in vegetative establishment. Protection from wave action may require a berm 8 to 10 feet wide located at the designed water level, or slope armoring if a high degree of protection is required.

Landforms and/or vegetation can be constructed or installed to influence the circulation of people coming to a wetland for recreational or conservation education purposes. These, in combination with elevated trails, boardwalks, and elevated observation platforms, will contribute to overall enjoyment of wetland environments.

If sport hunting or fishing is planned, associated structures such as access roads, restrooms, parking areas, blinds, earthen piers, and boat access points may be needed.

(d) Substrate sealing

Excessive seepage losses in wetlands usually result from selecting a site where the soils are too permeable to retain enough water for the planned function. This may be the result of inadequate site investigations in the planning stage, or the need for the wetland may be so important as to justify the selection of a permeable site. In such cases, plans for reducing seepage losses by sealing should be part of the design.

The problem of reducing seepage losses is one of reducing the permeability of the soils to a point where the losses become tolerable. Losses may be reduced by methods such as compacting of onsite soil material, clay blankets, bentonite, chemical additives, and flexible membranes. The choice of method will depend largely on the proportions of coarse grained sand and

Figure 13-18 Islands provide habitat for both waterfowl and upland species

gravel and fine grained silt and clay in the soil.
The materials to be sealed should be thoroughly investigated before a sealing method is selected. In some cases, it may be necessary to have a laboratory analyze the materials. See Chapter 11, Ponds and Reservoirs, for a discussion of the sealing methods listed above.

(e) Vegetation design

In vegetation design, care should be taken to include plant species that match the wetland objectives and that will perpetuate themselves in the wetland landscape. Figure 13-19 is a flowchart to aid in making decisions regarding when to include vegetation within the design. Vegetation used on dikes should be compatible with the integrity of the dike and function(s) of the wetland. Plant materials should come from local ecotypes and genetic stock similar to that within the vicinity of the wetland. Design should allow for diversity and a variety of habitat features to meet functional objectives. Local wetland plant communities should be inventoried to determine which species are adapted for the area.

(1) Factors affecting plant selection

During the design phase of a wetland, 10 critical factors should be considered regarding vegetation on the site:

(i) Goals and objectives—These should have been identified and firmly established in the planning phase.

(ii) Water supply—This includes fluctuations, inundations, flooding levels and durations, tidal regimes, pool stability, water quality, water volume, and inlet and outlet locations and types.

(iii) Substrate—Requires consideration of soil texture, interactions among substrate, slope, and elevation, and any other planting substrate (subsoils, acid mine tailings, salinity, alkalinity) that may be encountered.

(iv) Water depth—This is directly related to substrate saturation and water supply, and to the use of water control structures. Depth of water will affect the vegetation species used.

(v) Slope—A 6:1 or gentler slope is recommended in most cases; this is highly wetland-specific because cases of 10:1 to 15:1 are common. There is a direct relationship between slope gradient, slope stability, and plant species growth and survival.

(vi) Length of growing season—The growing season must be long enough for the selected plant to reach full growth potential and to produce mature seed.

(vii) Surrounding habitats and land uses—The vegetation must be compatible with surrounding land uses. Vegetation selection should avoid attracting nuisance animals that may be incompatible with surrounding land uses.

(viii) Wind and wave energy—Applies to wetlands associated with bodies of water. May adversely affect plant establishment. Select plants that will break wave action and protect shorelines.

(ix) Currents and velocities—Applies only to wetlands adjacent to steep gradient streams and large rivers. May adversely affect plant establishment. Select plants that will break wave action and protect shorelines.

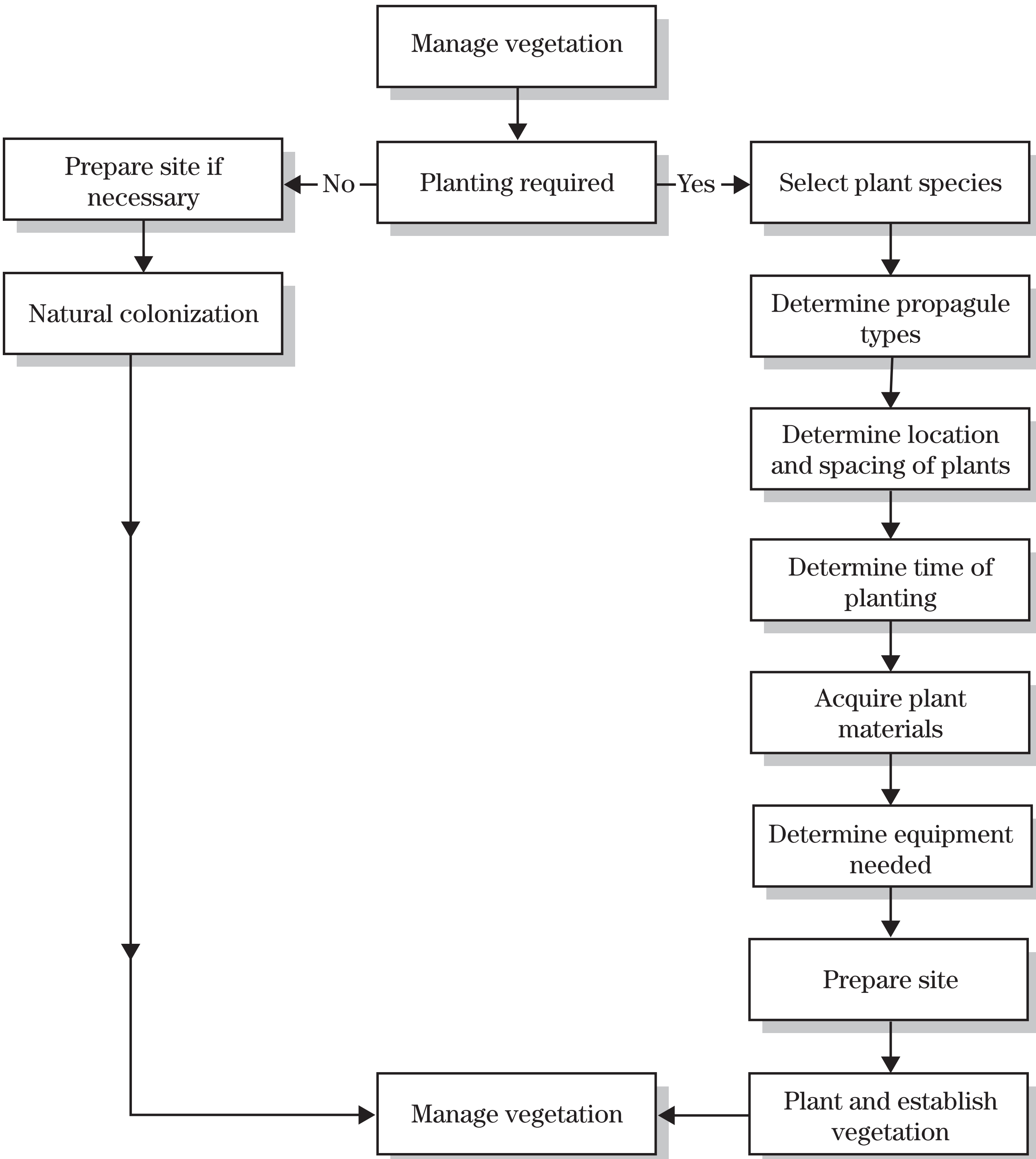
(x) Costs—Vegetation costs will vary greatly, depending upon technical decisions related to planning and design and to the difficulty of working on the site.

(2) Natural colonization

Natural colonization is defined as the process in which plant materials grow naturally on a restored or created wetland site. Natural colonization is generally the most successful and least expensive means of vegetating a wetland site (fig. 13-20). However, it requires the availability of plant propagules of desired species that are present at the site, or will be carried to the site by water, wildlife, or wind. Upstream or adjacent plant sources should have been examined during planning to determine the best species to encourage.

If the designer is unsure of the site's ability to vegetate naturally, he or she may want to leave the site to its own resources for a period of 12 months to determine its natural capacity. If by that time it has not vegetated naturally, planting should be considered.

Figure 13-19 Flowchart for vegetation design decisions



(3) Planting

Monostands of wetland plants do not generally address most wetland functions. Such stands are encouraged in certain cases, where only one species will survive, where pulpwood timber production is the only function targeted, where monostands are needed to maximize endangered species habitat, and where monostands are used to take up contaminants for water quality improvements. This should be done with extreme caution to avoid concentrations of contaminants to harmful levels.

Soil bioengineering (see EFH, chapters 16 and 18) offers additional restoration and erosion control technology that encompasses the use of live cuttings or plants. Quickly established, vegetative roots bind unstable soils into a coherent mass, while the top growth of established plants serves other benefits. It is common to find complex planting plans developed for wetlands similar in concept to those developed for parks and other recreational sites. Good planting plans provide for diversity, allow multiple function uses, emphasize natural settings, and use native wetland vegetation.

(i) Wooded wetlands—In most wetland situations, encouragement of natural colonization of diverse vegetation or the planting of a group of species is desirable. Designs should include compatible species that tolerate the site's hydrology, elevation, water depth, and soil conditions, and that address the wetland project's goals and objectives (fig. 13-21).

Examples: For a floodplain forest restoration in Kentucky, a typical design could call for equal numbers of pin oak, *Quercus palustris*; American elm, *Ulmus americana*; American sycamore, *Platanus occidentalis*; black gum, *Nyssa sylvatica*; baldcypress, *Taxodium distichum*; and sweet gum, *Liquidambar styraciflua*, on 10-foot centers (435 tree seedlings/acre, 72 trees of each species/acre). Trees should not be planted in straight monostand rows; instead, species should be interspersed and randomly planted to encourage maximum diversity. This reforestation mixture is designed for variable slope areas. In other bottomland fields of uniform elevation subject to flooding, species selection should be based on the upper level of flooding. Species should have similar

Figure 13-20 Natural colonization is generally a less expensive option.

tolerances to flooding, require similar soil conditions, and grow at similar rates. Generally, more wet tolerant species can be planted on drier sites but not viceversa. Refer to table 13-11 for example relative to lower Mississippi delta.

In table 13-11, long duration flooding or soil saturation lasts for several months at a time. Short duration occurs for a few days to a few weeks at a time. For a Pacific Northwest riparian woodland, the use of black cottonwood, *Populus trichocarpa*; western sycamore, *Platanus californica*; Pacific willow, *Salix lasiandra*; Pacific alder, *Alnus pacifica*; and common chokecherry, *Prunus virginiana*, may be a recommended species mixture. With trees planted on 10-foot centers, and shrubs planted on 5- to 8-foot centers, cluster planting will provide habitat at several levels (canopy, understory, shrub layer, ground) and dense cover for nesting.

(ii) Herbaceous wetlands—Regionally specific seed mixtures are commonly used to seed wet meadows, wet prairies, and fresh marsh fringes. While standard seed mixtures are given in several published planting guides, seed mixtures should generally be tailored to the wetland's targeted functions (fig. 13-22).

Examples: If waterfowl habitat is a targeted function in the Southeast and natural colonization is unfeasible, seed mixtures of scarified softstem bulrush, *Scirpus validus*, and American threesquare, *Scirpus americana*; seeds of sedge, *Carex spp.*; and root stocks of California bulrush, *Scirpus californica*, hardstem bulrush, *Scirpus acutus*, and alkali bulrush, *Scirpus robustus*, could be included in the planting design. For root stock, planting should be on 1- to 3-foot centers, and the seed mixture should be broad-

Figure 13-21 Plant species must tolerate site conditions.

Table 13-11 Flood tolerances of several species in the Lower Mississippi Delta

Long duration flooding (weeks to months)		**Short duration flooding** (days to weeks)		
January-June	January-May	January-May	January-April	January-March
cypress	green ash	sweetgum	sawtooth oak	shumard oak
overcup oak	Nuttall oak	water oak	sycamore	cherrybark oak
water hickory	persimmon	willow oak	cottonwood	swamp white oak

Figure 13-22 Species typical of herbaceous wetlands

cast over the vegetative plantings.

(4) Species selection and propagule types

Certain plant species will be better suited to achieving a successful wetland, depending upon planning objectives and the type of wetland to be restored or built. Desirable characteristics of such species include competitiveness, seed production, and dense root mats to stabilize the newly established wetland. The use of native or well-naturalized plant species should be encouraged. Ecological impacts of using exotic vegetation are still not well understood in most regions. In general, plant species chosen should simulate closely a nearby wetland of similar type. For example, if a bottomland hardwood is selected as the wetland type to be restored, plant species chosen should reflect bottomland hardwood community composition on nearby sites at similar elevations and hydrologic conditions.

(i) Wooded wetlands—Woody plantings (trees and/or shrubs) come from five sources: seeds, cuttings, bareroot plantings, container stock, and dormant stub plantings. In addition, plant materials can be obtained from wetlands that are being altered.

Where seed sources such as acorns are available, these should be harvested in the fall of the previous year. They can either be stored in a cool, dry place until spring planting and then broadcast immediately onto a prepared soil bed, or inserted into shallow holes punched into the substrate. Seeds of hard mast species should be planted on approximately 3 to 10 foot centers.

Where willows, cottonwoods, poplars, and sycamores are the species of choice, 12-inch or longer cuttings can be taken from dormant live trees. These can be stored in moist sand until planting, or they can be planted immediately on the new site by inserting cuttings on 3- to 10-foot. centers. Planting dormant 6-foot (3-6 inch diameter) stems from cottonwoods and willows is also an effective way to establish woody species quickly.

To vegetate a wooded site more rapidly and to ensure greater survival of the initial plantings, transplanted bareroot seedlings can be planted. These will bypass decades of early successional stages and allow a floodplain forest, bottomland hardwood, or riparian woodland to grow and mature. Wetland bareroot seedlings must be planted so that roots reach the water table and the seedlings will not die from drought stress before they have a chance to establish a viable root system. These seedlings should be planted on centers ranging from 3 to 10 feet. Bareroot stock does not store well and should be used as soon as it is dug from the nursery or donor wetland. Bareroot wetland stock lends itself very well to mechanical planting using modified commercial tree planters; and where the substrate is firm enough to allow the use of equipment, planting is both faster and more economical.

Container stock is the most expensive, but also the most reliable means of vegetating a wetland site. The soil ball remains intact around the root system, greatly reducing stress to the newly transplanted seedling. One gallon container stock is usually easy to handle in the field and can be maintained in a nursery for an indefinite period of time until planting conditions are optimal. Tube planters and flats or similar smaller containerized seedings can also be used. Container stock should be planted on centers that range from 3 to 10 feet.

(ii) Herbaceous wetlands—Herbaceous wetlands contain grasses, forbs, sedges, bulrushes, cattails, reeds, and other perennial species that propagate by either seeds or vegetative stock, such as tubers, rhizomes, or bulbs. These species also lend themselves to natural colonization most readily, and frequently are hardy and aggressive. If planting is required to stabilize a site rapidly or to accomplish mitigation, seeds or vegetative parts can be used to vegetate the wetland. Seeds are the least expensive to plant, as they are generally broadcast on the saturated surface of the wetland. However, seed sources can be unreliable and scarce. Vegetative propagules can be obtained by digging whole plants and cutting apart roots, rhizomes, tubers, and other plant parts for disking in, hand planting, or broadcasting on the new wetland site.

(5) Propagules

Plant materials are generally obtained from two sources: donor wetland sites, and nursery grown stock. Use of donor wetlands to obtain seeds or young plants will eventually affect the health and vigor of the donor stand, regardless of the care taken in spacing and location of plant removal areas. Removing plant materials from donor stands is not recommended unless commercial sources are not available. If donor stands are used, care should be taken to prevent degradation of that wetland.

Nursery grown stock is generally the most reliable and ecologically appropriate way to obtain plant materials. Private wetland nurseries are becoming more widespread and can custom propagate stock for wetlands. All propagule types discussed in the previous section can be provided commercially, but the most common types are seeds, container stock, or bareroot stock (fig. 13-23). Specifications for plant material to suit the wetland objectives and design should include design needs such as plant age, stem height, root development, and container size. The American Nurseryman's Association provides an industry standard for plant material.

Figure 13-23 Bareroot nursery stock *(U.S. Fish and Wildlife Service)*

Examples: A clump of bareroot softstem bulrush, Scirpus validus, could be specified to be not less than 6 months old and 4 inches in clump density, with six live stems having attached living roots. A container grown water oak, *Quercus nigra*, seedling could be specified to be not less than 2 years of age and well rooted in a 1-gallon biodegradable pot, with a stem height of not less than 3 feet Such specifications are very important if plant materials are to be contracted for the new wetlands.

(6) Time of planting

Time of planting is regionally specific, but is critical to the initial survival of the new wetland. Regional planting times are well known by local specialists, and they should be consulted if written guides are not available in the local SCS office. Generally, planting is best done during dormant season while the ground is not frozen. Losses from heat stress and drought will occur when bareroot stock is planted in the hot summer months. Consult the FOTG for planting times.

(7) Site preparation

Once the wetland area has been shaped and graded, the site should also be disked, harrowed, and otherwise prepared for sowing of seeds or planting root stock or seedlings. While these preparations are being made, whatever sod amendments (for example, slow-release all-purpose fertilizers and ground limestone) that soil analyses conducted during planning have shown to be needed should be incorporated into the soil. Depending on the planned species and water level management, it is often a good idea to release water onto a site to facilitate soil setting prior to planting, especially where slopes are critical. This can aid in the prevention of high spots and possible vegetation loss.

(8) Equipment

Seedbed preparation and planting in wetlands generally do not require specialized equipment. In most cases, standard farming equipment (tractors, disks, harrows) can be used in a wetland, depending upon the firmness of the substrate and on whether or not the water source is fully applied to the site at the time of planting.

Modified tree planters can be used for bareroot wetland tree and shrub species. In wetlands where soil is saturated at the time of planting, the commercially available tracked or light footpressure equipment is suitable for planting such sites. Where mud is soft and seeds of chosen species are used, aerial seeding may be necessary. In soft substrates where transplanting of plant materials is required, hand planting with dibbles has been found to work quite well. Designs and specs must include equipment requirements to be sure that the job is done correctly without damage to adjacent existing wetlands or surrounding areas (fig. 13-24).

(9) Plant installation

Planting considerations include spacing, sizing, timing of planting, and species-specific requirements. Additional considerations may include hydromulching, adsorbents, and the need for nurse or cover crops to protect the desired species until they are well established (fig. 13-25). Hydromulching is more commonly used in wetlands in the Western United States, and is an aid where water shortages may occur in early stages of site establishment. Hydromulching may include in the slurry: seeds, fertilizers, chopped mulch (hay, straw), and tackifiers to hold the mulch to the substrate surface. Seeds can be coated in advance with adsorbents to give them a better chance of survival during germination. This should be a design consideration where planting is expected in summer months or in the Western United States. Refer to commercial hydromulching guides to write design specifications.

Nurse crops may be valuable in protecting the new wetland, especially on sandy soils or where climax forest is the desired wetland type. Planting a nurse crop such as ryegrass in winter or Bermuda grass in summer (or other regionally specific nurse crops) will provide erosion control. Refer to FOTG for planting rates.

Examples: Bermuda grass, legumes, and annual small grains are planted as nurse crops along with young

Figure 13-24 Modified planter for acorns

bottomland hardwood seedlings. Early successional stage willows and cottonwoods are planted on streambanks, and climax floodplain species are encouraged to colonize or are planted after the willows and cottonwoods have stabilized the bank.

(10) Nuisance species control

In many regions, grazing by geese, nutria, muskrats, deer, and several species of ducks on establishing wetland plants may have major impacts on the new wetland. Ways to prevent degradation can be obtained from local officials of the Extension Service and fish and wildlife agencies.

(f) Structural design example

A wetland is to be restored in a field that has been drained with subsurface drainage and cropped for 20 years. The desired function of the wetland includes and wading birds. To accomplish this function, the wetland must provide adequate food at water depths less than 1 foot and adequate cover for protection.

The soils in this area were determined to be drained mineral hydric soils with a Unified Classification of CL to a depth of 4 feet. The permeability was determined to be slow.

Plant species of nearby wetlands were inventoried and it was determined that natural colonization will occur and will provide adequate food and cover.

A survey and a topographic map were made of the site, and a stage-area-storage curve was plotted. It was determined that the restored wetland could cover 2 acres if a dike was constructed at the lower end. The contributing drainage area was determined from a USGS quadrangle map to be 24 acres. This area is under a conservation plan. Land use is alternating row crops with conservation tillage and hayland. Water quality is therefore expected to be good.

A water budget was developed. Inflow will consist of storm water runoff and direct precipitation. Outflow will consist of evapotranspiration and storm water

Figure 13-25 Attention to spacing, size, time of planting, and other considerations encourages plant establishment

outflow. Because of the slow permeability of the soil the seepage losses were judged to be negligible. Using local data, it was determined that the contributing drainage area would produce sufficient runoff to maintain the desired depth for 10 months out of the year. A deficit will occur in August and September, but adequate water will be available to support wetland vegetation.

The structural components to be designed are:

- a drain block
- a water control structure
- an emergency spillway, and
- a dike.

(1) Design of the drain block

The landowner reported that the subsurface drain to be blocked served only this area and that the blocking of this drain would have no adverse impact on other drainage systems. The landowner identified the approximate location of the subsurface drain. The exact location of the intersection of the drainline and the centerline of the proposed dike will be found during construction. Fifty feet of the drain downstream of the centerline of the dike will be removed. Fifteen feet of the drain upstream of the centerline of the dike will also be removed. Both ends of the existing subsurface drain will be plugged by installing a plastic end cap. The backfill in the drain trench under the dike will be compacted to a minimum density equivalent to the density of the surrounding material.

(2) Design of the water control structure

The water control structure will be a pipe drop with a flashboard riser (fig. 13-26). It will maintain the desired water level in the wetland and protect the emergency spillway by lowering the pool 6 inches below the crest of the emergency spillway in 24 hours. The area of the pool at the flashboard riser is 2.0 acres, and the area at the crest of the emergency spillway is 2.8 acres.

To calculate the required capacity of the pipe drop, multiply the depth of water to be removed in feet by the average basin surface area in acres and divide by the time of removal:

$$(0.5 \text{ feet x } 2.4 \text{ acres})/\text{day} = 1.2 \text{ acre-foot/day}$$

One acre foot per day is approximately equal to 0.5 cfs; therefore the required capacity is 0.6 cfs.

The required diameters of the riser and barrel may be determined by sizing the barrel to carry the required flow using equation 13–17, and then sizing the riser to assure weir control at that flow using equation 13-15. To use the pipe flow formula (eq. 13–17) refer to Chapter 3, Hydraulics, for the head loss coefficients or use the Exhibit for Discharge of circular pipes flowing full. For smooth pipe, such as PVC plastic with an N value of 0.012, read directly that a 6 inch diameter will handle 0.6 cfs at a pipe slope of 1.5 feet per 100. For weir flow, a 12-inch flashboard will discharge 1.1 cfs at the design depth of 0.5 foot, and at a minimum flow depth of 0.2 foot the weir length of a half round 12-inch riser plus the 12-inch flashboard will carry 0.7 cfs. A 12-inch half round riser with flashboard and a 6-inch barrel were selected. Recommend setting the emergency spillway crest 0.7 foot above the flashboard riser.

The elevation of the crest of the riser will be set at the elevation of the desired permanent water level.

(3) Design of the emergency spillway

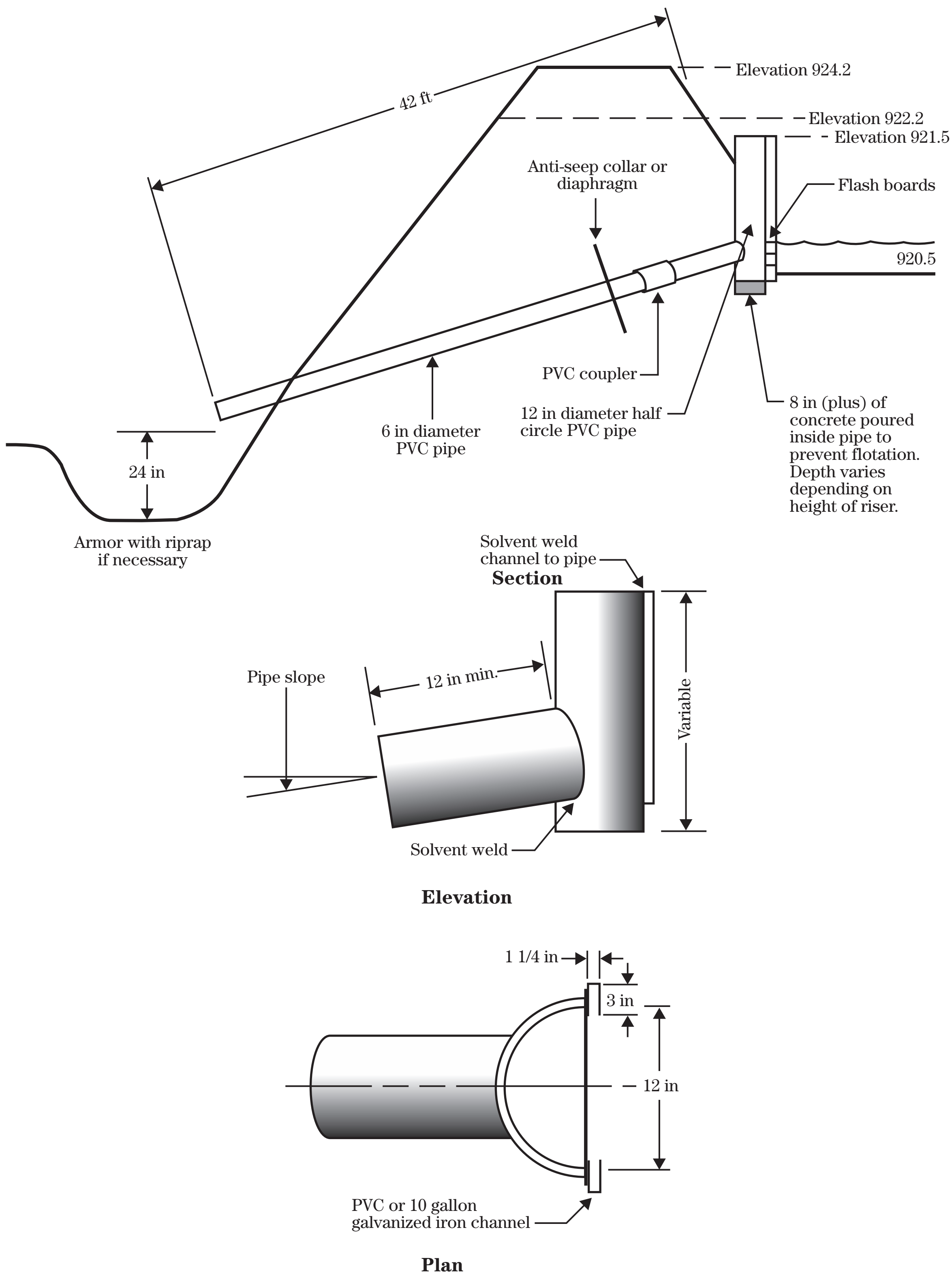
The crest of the emergency spillway will be set 0.7 foot above the crest of the riser of the pipe drop inlet. Using chapter 2 of the EFH it was determined that the 10 year - 24 hour storm resulted in 4.1 acre-feet of runoff with a peak discharge of 22 cubic feet per second. The dimensions of the emergency spillway were designed using the procedure found in chapter 11 of the EFH. The width (b) will be 20 feet with required stage (H_p), 1.2 foot.

(4) Design of the dike

The proposed centerline of the dike was located on the topographic map.

The dimensions of the dike are determined using the maximum design water height. The maximum design water height of 2.9 feet is the sum of the water depth (1 ft), the distance between the crest of the riser and the emergency spillway (0.7 ft), and the stage in the emergency spillway (1.2 ft). Table 13-6 recommends the minimum dimensions of the dike, top width of 4 feet, the side slope of 2.5:1, and the minimum freeboard (H_f) of 0.8 foot. No additional freeboard for wave action is needed.

Figure 13-26 Principal spillway with flashboard riser



The settled settled elevation of the top of the dike will be the elevation of the high water stage (H_w) plus the freeboard (H_d). The constructed elevation of the top of the dike will be the settled elevation plus the allowance for settlement (H_s). Since this dike is to be built with a dozer, the H_s will be 10 percent of the difference between the settled elevation of the dike and the elevation of the normal ground along the centerline of the dike. This will vary along the centerline.

Foundation preparation will consist of stripping 1 foot from the base area of the dike.

Plans and specifications will be prepared. The plans will include a plan view, profiles along the centerline of the dike, water control structure and emergency spillway, and a typical cross section of the dike. Specifications will include site preparation, excavation, earthfill, pipe material, pollution control, and vegetation establishment. A list of the items needing inspection will be included.

650.1304 Implementation

Implementation encompasses all activities necessary to achieve the desired functions and values in the wetland.

Careful site examinations conducted during the planning and design phases play an important role in preparing an implementable design. Even with intensive site examinations, design modifications may be necessary during implementation to ensure success of the completed project. This will require communication and understanding between the planners, designers, landowners, inspectors, and contractors.

For contracting procedures and specifications refer to the SCS Contracts and Grants Manual, Field Office Technical Guide, and National Engineering Handbook. Wetland construction contracts can be drawn up separately from plant materials contracts for the wetland, or one contractor may be selected to restore or build the wetland through all phases. Where private landowners or groups are involved in the wetland project, they may provide their own equipment and labor, or may contract privately with a construction firm. Whatever techniques and equipment are used to accomplish the project, specifications and quality controls over actual construction and implementation need to be clear and enforceable.

(a) Quality control

Quality control is the responsibility of everyone involved in a project. The quality control process begins at the time of initial planning and site selection and continues through the subsequent steps of design, contracting, construction, and operation and maintenance.

Attributes such as function, layout, size, and quality are determined in the planning stages. These attributes are then integrated into construction drawings, specifications, construction inspection plans, and operation and maintenance plans. Requirements for the quality of materials, construction tolerances, safety, and pollution control during construction must be included in the project plans, specifications, or contract documents during the design and contracting phases.

Standards, specifications, and procedures have been established for various kinds of materials and construction methods. The scope will vary with project complexity and contract form. Inspectors and other quality control personnel must be aware of the grades of materials and standards of workmanship recognized as appropriate for the various kinds of construction that will be employed.

Standards, specifications, and procedures have also been established by Federal, state, and local governments limiting actions that adversely affect the environment, prescribing methods for controlling erosion and sediment, minimizing pollution of water and air, controlling noise levels, protecting natural features, protecting archeological and historical sites, protecting fish and wildlife, providing for sanitation, and controlling the use of pesticides. Quality control verifies that all the components of the project comply with the project requirements, standards, specifications, and established procedures.

Quality control activities take many forms. They consist of surveying to establish whether the wetland has been constructed to within the specified tolerances to the designed line and grade, checking materials against preapproved supply lists or material specifications, testing materials for specified strength or density, computing as-built quantities, reviewing contractor records on payroll, and meeting safety and health requirements.

The magnitude and intensity of the quality control activities will vary with the scale of the project, landowner or sponsor requirements, and method of contracting. A very simple project may require little onsite activity, whereas a complex project may require a specially qualified full-time inspector.

(b) Site construction

General construction practices described in EFH Chapter 17, Construction, also apply to wetland construction. Similarly, specific construction requirements and considerations for the individual structural and earth moving components also apply.

(1) Dewatering

Proper construction of a proposed project often depends on maintaining the proper site conditions during construction. Low ground pressure vehicles, either rubber-tired or tracked, or equipment that can work in water may be required. Construction sites that have standing water may require dewatering and drying before equipment can access the site with sufficient maneuverability to begin construction. The methods used may vary with site conditions and location. Applicable methods may include diversion of inflow to the site, drainage by gravity using ditches through the site, pumping from trenches or sumps adjacent to any foundation area, and for extreme conditions, a system of wells or well points. Scheduling construction for normally drier periods of the year may also be effective.

(2) Pollution control

All necessary steps should be taken to control erosion and minimize the production of sediment and other pollutants of water and air during construction operations. Pollution control items include, but are not limited to the following:

(*i*) Stage clearing and grubbing operations to limit the size of the disturbed area.

(*ii*) Install terraces or diversions to divert water away from work areas or to collect runoff from the work area:
- Above and below borrow areas
- Above emergency spillway area
- Above storage areas

(*iii*) Use waterways for the safe conveyance of runoff from fields, diversions, and other structures.

(*iv*) Control pollution from access and haul roads or construction staging area by the following means:
- Contour roads
- Dust control
- Erosion control - turnouts, pipe culverts
- Vegetation of disturbed areas
- Avoid removing trees, shrubs, and important vegetation

(*v*) Schedule the excavation and transport of soil materials so that the smallest possible areas will be unprotected from erosion for the shortest time feasible.

(*vi*) Use culverts or bridges where equipment must cross streams.

(*vii*) Use sediment basins and vegetation to settle and filter out sediment from eroding areas.

(*viii*) Use straw bale filters or silt fences to trap sediment from areas of limited runoff.

(*ix*) Complete work in a timely sequence.

(*x*) Provide winter or seasonal shutdowns.

(*xi*) Provide clean and sanitary conditions at the work site at all times.

(*xii*) Seed and mulch, temporarily and permanently, in a timely manner.

(*xiii*) Provide watertight tanks or barrels or construct a sump sealed with plastic sheets to dispose of chemical pollutants (such as drained lubricating or transmission oils, grease, soaps, asphalt,) produced as a byproduct of the project's work. At the completion of the construction work, sumps shall be voided without causing pollution.

(*xiv*) Sanitary facilities such as pit toilets, chemical toilets, or septic tanks shall not be placed adjacent to live streams, wells, or springs. They should be located at a distance sufficient to prevent contamination of any water sources. At the completion of construction work, facilities shall be disposed of without causing pollution.

(*xv*) Fire prevention measures shall be taken to prevent the start or the spreading of fires which result from project work. Fire breaks or guards should be constructed as needed.

(*xvi*) Follow local and state regulations concerning the burning of cleared material or disposal of other materials.

All pollution control measures and works shall be adequately maintained in a functional condition as long as needed during the contractor operation. All temporary measures should be removed and the site restored to as near the original condition as practical.

(3) Dikes and levees

Foundation areas for all dikes should be cleared of trees, stumps, logs, roots, brush, boulders, or organic matter. Channel banks and sharp breaks should be sloped no steeper than 1.5:1. Organic soils should be removed from the foundation area, except where the dike will be constructed from organic soil or geotextiles are used to improve foundation conditions. For dikes constructed in organic soils, the top 2 feet from a borrow area should be placed at both toes of the embankment to retain the softer material placed in the fill.

A cutoff trench, if planned, should be excavated approximately along the centerline of the dike. The trench should be backfilled with the least permeable soil available and compacted. The excavated material, if suitable, may be used elsewhere in the dike fill. Where the dike crosses old channels, the soft, unsuitable material should be removed from the base section. The bank of the old channel should be sloped no steeper than 1.5:1 before placing the new fill.

Dikes are often constructed from spoil excavated from drainage ditches. The spoil is placed to the required height and shaped. If the spoil is wet, allow for draining and drying before shaping. Where additional stability by compacting is needed, the dike should be constructed in stages.

Generally, the borrow is taken from the waterside of the dike. Ditches are sometimes over excavated to obtain additional fill material. At times, fill must be obtained from the landside, especially when this practice eliminates excavating through highly permeable strata on the waterside, which could result in excessive seepage through and under the dike during flood stages.

A borrow ditch on the landside may be planned as a unit of the interior drainage system and the excavated material used in the dike. Such a ditch should be far enough away from the dike to eliminate undermining. Physical features, such as roads and railroads, or the lack of suitable material may require that the borrow be transported from a distant point.

If a borrow ditch located along the waterside is not part of the interior drainage system, it should be interrupted at intervals to slow the velocity of the water moving along the toe of the fill.

Such unexcavated plugs also serve as crossovers for maintenance equipment at low water stages. They should be spaced at intervals not to exceed 1,320 feet and should be at least 25 feet wide.

(4) Conduits

Any conduit through a dike should be placed on a firm foundation. Selected backfill material should be placed in layers 6 to 8 inches thick around the conduit and each layer thoroughly compacted. Compacting can be a problem because of wet conditions. The conduit itself should be watertight. Anti-seep collars or drainage diaphragms should be used for added control of seepage along the surface of the conduit.

(5) Pilings

Pilings may be required in wetland projects to support different components, such as access walkways, docks, and pipes.

Wood piles shall be of sound wood, free of decay and insect attack, and of a size compatible with the intended use. For guidance on installation and specifications, consult SCS National Engineering Handbook (NEH), Section 20, chapters 2 and 3, and the American Society for Testing and Materials (ASTM), Material Specification D-25.

(6) Construction equipment

Consideration should be given to types of equipment to be used for earth moving, site preparation, and seeding or planting the site (fig. 13-27). Table 13-12 lists some types of equipment used in wetland sites where flooding has not yet occurred, where soils are already saturated, or where standing water already exists.

(c) Wetland soils as sources of plant materials

Wetland topsoils are unique sources of plant materials. They are primarily available in freshwater areas.

Deeply buried wetland seeds may survive for up to 70 years in wet soils and, once exposed to the top few inches of soil, will germinate and provide for abundant natural colonization. In handling wetland topsoil, avoid compaction of undisturbed or stockpiled soils.

Figure 13-27 Heavy equipment is often used on wetland projects

Table 13-12 Construction equipment vs. site conditions

	Dry land	Saturated soil	Standing water
bulldozer	X	X (sand)	
backhoe	X	X	
hydraulic excavator/trackhoe	X	X (sand)	X*
tree planter	X	X	
root grubber	X		
disk/plow	X		
harrow	X		
rototiller	X		
sub-soiler	X		
broadcast seeder	X	X	
drill seeder	X		
light ground-pressure equipment		X	X*
special wide tracks		X	X*
rubber-tracked equipment		X	X*
scraper (road grader)		X	
sled		X	X*
floating platforms			X
hydraulic dredge			X
bucket dredge		X	X
dragline dredge		X	X
dewatering trencher		X	X

* Only applicable under shallow water less than 2 ft. deep.

If an herbaceous wetland is to be created as mitigation for the loss of a similar wetland, up to 2 feet of soil from the existing wetland may be removed and transported to the new site. The receiving sites are excavated to grade to accommodate the additional topsoil from the donor wetlands. Then the sites are allowed to grow naturally from the seed bank present in the topsoil.

When wetland soils must be removed from the existing site and stockpiled for up to several months, store them in a low, undisturbed area where saturated conditions can be maintained. Line the storage area with plastic to prevent water percolation and oxidation of the sod. This will also protect the wetland seed bank within the stockpiled soil.

(d) Vegetation

(1) Plant material

If the wetland is to colonize naturally, there are no additional requirements for vegetation other than possible site preparation during implementation. If the wetland is to be planted, plant materials should be transported to the wetland site and temporarily stored there, under saturated or standing water conditions if necessary. The easiest means of transporting and holding bareroot, cutting, or root stock plant materials just prior to planting is in plastic containers or bags that will prevent moisture loss. Seeds should remain stored in cool conditions away from the site until planting is to occur. Container stock, the bulkiest of plant materials to move to a planting site, should be placed in shade shortly before planting and kept moist at all times.

(2) Site preparation

Disking and harrowing of the site should take place just prior to planting, and after all other earth moving and shaping is completed. If earth moving is completed several months prior to the recommended planting time, do not disk and harrow until time to plant. If transplants are to be used, incorporate fertilizer and/or limestone, if needed, during disking and harrowing prior to planting. Care should be taken to prepare a substrate that will maximize root growth in the shortest period of time.

(3) Planting

Planting the wetland is generally the final task. Care must be taken to follow recommended spacing, random placement for diversity, and all other specifications set forth in the design to achieve the desired wetland objectives. In certain cases, especially in the semi-arid West, once planting commences, temporary to ensure germination, growth, and survival until root systems are well established.

650.1305 Monitoring

Monitoring is necessary to measure wetland success, both in the short- and long-term. Another important function of monitoring is to identify the need for midcourse correction. If monitoring indicates that a goal is not being met, corrective actions should be taken.

To achieve project goals established during the planning stage, monitoring and management should be ongoing. Specific monitoring and management objectives and their related activities will vary depending on wetland type, design, and desired functions. Criteria must be established to determine success at meeting project goals, but those criteria must allow for the dynamic and uncertain processes within wetlands. Objectives should be flexible enough that the wetland can be managed to achieve benefits even if unforeseen factors limit the realization of planned wetland functions. Both short- and long-term objectives and criteria should be established. Timeframes will vary according to wetland functions and components.

(a) Criteria and baseline information

Fundamental to monitoring is the establishment of success criteria and wetland baseline conditions. Success is the extent to which the wetland meets the goals established during the planning stage. Clear and concise criteria, both quantitative and qualitative, should be established for each wetland goal in order for monitoring to provide effective measures of success. For example, a wetland established to control Sediment may require regular monitoring to determine if sediment has been trapped to the degree expected. Initial basin elevations (baseline) need to be compared to subsequent elevation measurements to see if sedimentation criteria are successfully being achieved. If the goal was collection of sediment at a specific location, the actual depth should be compared with the goal. The desired depth is the quantitative criteria; the degree to which the criteria were met is the level of success. On the other hand, the success of a wetland established for aesthetics may require qualitative criteria.

Monitoring also allows planners to estimate change over time. To accomplish this, baseline conditions must be measured and recorded for each project goal to be monitored. Depending on the nature of the wetland, two types of baseline conditions may be needed, previous conditions and as-built conditions. If the wetland is an enhancement project or was constructed as mitigation for other wetland loss, the pre-alteration conditions at the enhanced site or at the site where wetland losses will occur should be recorded so that monitoring can determine if the expected gain or replacement of wetland function has been achieved. However, if a wetland is created or restored at a site where none has existed for a considerable length of time, only as-built conditions need be recorded. As-built conditions are the actual structural and functional conditions existing at the site when work was completed.

The amount of baseline information needed will vary, depending on the number and type of planned wetland functions and on the funding available. Baseline conditions should be recorded for each wetland characteristic to be evaluated for success or monitored for potential corrective action. The methods used to collect baseline information should be the same as or complementary to the methods established for later monitoring procedures. In a complex and well-funded project, the information may consist of detailed planimetric and contour maps, an assessment of site hydrology, a complete description of vegetation, information on invertebrate and wildlife use, a photographic record, and soil information.

A site plan should be made showing the location, general shape and area of the wetland basin, areas of impounded water, locations of dikes built or removed, water inflow and outflow structures, and general design components. In addition, a narrative description of the soils and vegetation and a description of any deviation from the original design are required. The construction maps often can be modified to serve as the sketch map. If project goals include habitat or general wetland functional improvement, a WET or HEP assessment may be appropriate. A photographic record is inexpensive and is recommended.

(b) Periodic monitoring

Periodic monitoring provides data to compare with baseline conditions for determining the rate of wetland development and for measuring short- and long-term success. The characteristics monitored should reflect the project goals. For example, if one goal is to provide nesting habitat for a specific bird species, annual counts of nesting pairs should be made. Criteria for success may be fixed or relative. For example, fixed criteria for nesting pairs might be 10 nests after the first year, 20 after the fifth year, and 25 after the tenth year. A relative criteria might be expressed as a 10 percent growth per year in nesting pairs over 10 years.

The frequency of monitoring will vary, depending on the goal and the probability that corrective management action is required. In general, more frequent monitoring is required during the 5 years immediately following project completion. During this period, the wetland is developing rapidly, and mid-course corrections are most likely to be required. One approach to monitoring is to visit the site frequently to make qualitative observations of general site conditions. During these visits, the wetland should be examined for major changes which may adversely affect the site (e.g., the development of unwanted vegetation, erosion, or changes in adjacent land use). If adverse conditions are observed, more intensive monitoring procedures may be instigated. Appendix B gives a site visit checklist to use for quick qualitative site monitoring.

When many wetlands are restored, enhanced, or created in the same general region, it is important to standardize the monitoring methods used. The use of consistent methods allows information from different sites to be compared and combined. The information is essential for developing better wetland designs and construction techniques for the region. All monitoring records should be archived and made available for future reference.

650.1306 Management

A wetland management plan is required for each restored, enhanced, or created wetland. The management plan should be developed in conjunction with the wetland restoration plan and should reflect the overall project goals and intended functions.

This section outlines the general concepts of wetland management for wildlife. This function is highlighted because:

- management information is readily available, and
- it is presently the reason many landowners restore, enhance or create wetlands.

Management should be aimed at realizing the objectives established for the wetland during the planning Objectives may be to establish certain vegetation species for timber harvest, food production, or habitat development; or they may involve water level management for flood storage, water supply, or recreation functions. As with success criteria and monitoring activities, they should be flexible enough for wetland benefits to be achieved even if unforeseen factors limit the realization of planned wetland functions.

Active wetland management may be required to make mid-course corrections of problems identified during regular monitoring. There also may be planned management procedures to enhance specific wetland functions (such as disturbing the wetland to retain characteristics of early successional stages).

(a) Prairie pothole management

Prairie potholes are extremely valuable fish and wildlife habitats simply because they are diverse, dynamic, and very productive (fig. 13-28). They are diverse because the prairie pothole region contains a variety of freshwater habitats ranging from small and shallow ephemeral wetlands to large, permanent, deep water marshes. Prairie wetlands are dynamic because they are always changing and they offer a wide range of economic, biological, and hydrological values.

Figure 13-28 Wetlands that contain a mixture of open water and dense vegetation provide productive waterfowl

Finally, prairie potholes are very productive because they are subject to frequent environmental extremes such as natural drawdowns (sometimes through drought) and subsequent flooding. The natural drawdown/reflooding cycle is very important ecologically because it allows the recycling of nutrients which, in turn, maintain the productivity of these prairie wetlands.

Successful management of prairie potholes will recognize the diversity of these wetlands and their natural drawdown/reflooding cycles. Consequently, management plans designed for prairie potholes should maintain a variety of wetland types within a local area to allow natural drawdown/reflooding to occur. Efforts to increase water depths of historically shallow prairie potholes should be avoided since doing so would decrease the biological diversity within an area. Likewise, efforts to concentrate water within shallow wetlands should be avoided. Waterfowl and other water-dependent wildlife need a variety of wetland habitats at various times throughout the year. Converting most wetlands to semi-permanent or permanent wetlands would actually decrease the abundance and diversity of wildlife habitat.

Wild ducks are divided into two groups according to habitat requirements. “Diving ducks,” such as canvasback, redhead, scaup, and ring-necked duck, dive for food and usually do not feed on land. They nest in vegetation along the shore or within emergent vegetation over the water. The more common “puddle ducks” are represented by the mallard, shoveler, pintail, and teal. These ducks generally nest within a few hundred feet of water but can nest in hay fields or odd areas over a half mile from water. The hen takes the brood to open water after hatching.

Potholes that are overgrown with emergent vegetation (generally cattails) have only limited waterfowl production potential. In these cases, some temporary control of emergent vegetation may be obtained through the use of herbicides or late fall mowing. Where manipulation of water levels is feasible, especially in partially drained wetlands, water control structures can be installed to assist in vegetation control. Through maintenance of water depths of 3 1/2 to 4 feet, dense stands of emergent vegetation can be reduced. The most ideal waterfowl brood habitat is a wetland containing 50 percent open water and 50 percent emergent vegetation.

In most prairie potholes, dredging does not improve waterfowl and other wildlife habitat and should be avoided, especially where nesting islands and adjacent excavated deep water habitats are established in small ephemeral wetlands.

(b) Seasonally flooded impoundments for wildlife

These areas are typically flooded in the winter and drained or dried during the summer to improve waterfowl habitat (fig. 13-29). The vegetation can be categorized as either desirable for food and cover or undesirable because it interferes with the production of desirable plants. Species composition depends initially on whether a desirable seed source was already present in the soil or if establishment was required. Management activities that determine plant response of an established natural plant community are timing of annual drawdown, depth of flooding, disturbance by disking or plowing, and continuous flooding (fig. 13-30).

Maintaining vegetation beneficial to certain species of waterfowl in early succession through frequent soil disturbance or water manipulation may result in a predominantly annual vegetation community with high seed production. After 5 to 7 years, the vegetation will develop seed producing perennials. To reach this goal, disk the area every 3 years for the first 5 to 7 years, and less often after that.

Vegetation incompatible with planned objectives may be controlled by disking, burning, mowing, grazing, or biological or chemical procedures. For example, in the Northeast, purple loosestrife can be suppressed with repeated mowings and tillage, but it can be eliminated only by chemicals. The duration and degree of submersion are critical for control if flooding is used. Each control technique must be considered carefully. Prescribed burning must be carefully planned and carried out by a group trained in burning. A prescribed burn plan must be developed before burns are initiated.

In general, there are two types of drawdown, slow and fast. Slow drawdowns occur over a period of 2 weeks or more, and fast drawdowns occur within a few days. Slow drawdowns carried out early in the spring season produce a more diverse vegetative community. Slowly receding water favors diverse species germination. Fast drawdowns early in spring normally produce stands of similar vegetation. Slow drawdowns in late spring produce vegetation of greater diversity and density. Fast drawdowns late in the season may produce less vegetation because of higher soil temperatures when saturated soils become dry. In the South, early drawdown promotes smartweeds during early successional stages and yields greater total seed production. Mid-season drawdowns promote millets. Late season drawdowns promote sprangletop, beggerticks, panic grass, crab grass, and higher stem densities. Slow drawdowns produce greater density and diversity than fast drawdowns and prevent the displacement of wetland wildlife that occurs with fast drawdowns. Water level management should be coordinated with the arrival and departure of wildlife species or with habitat conditions, not with a calendar date. Manipulation of undesirable plants should be timed, whenever possible, so that decomposing vegetation can be used effectively bywetland invertebrates. These high protein organisms provide excellent food for waterfowl or shorebirds.

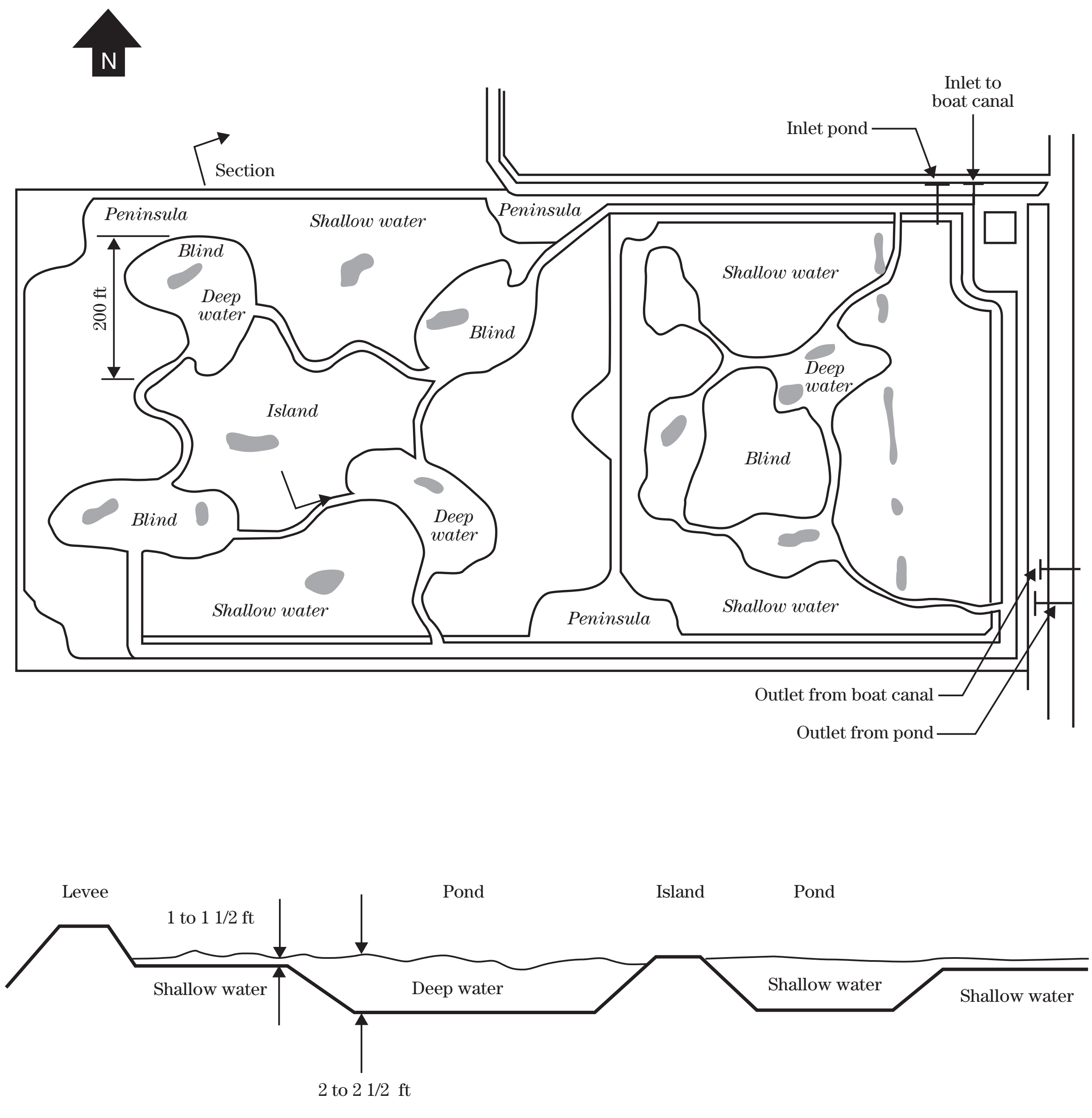
The complexity of water manipulation to manage vegetation emphasizes the importance of frequent monitoring. Frequent inspections allow for timely decisions to control the plant community composition.

Single chemical applications seldom result in complete control of undesirable vegetation. Ground equipment may cause unacceptable damage, and care must be taken to control drift and avoid damage to non-target species. Herbicide applications are usually costly as well. Biological control of undesirable vegetation using foraging insects holds promise for some species but should be planned by professionals in this field.

At northern sites where willow and cottonwood establishment may be undesirable, it may be controlled by mowing followed by shallow flooding. In southern areas, disking during the hottest days of summer can destroy seedlings. Disking 2 to 3 times during the growing season may be the most effective means of control. A good practice is to disk the site once every 3 to 4 years to maintain the site in an early successional stage. If larger saplings of up to 3 inches in

Figure 13-29 Enhanced wetlands provide important wildlife habitat in arid landscapes

Figure 13-30 Diked wetlands are often designed with various water depths to increase vegetative diversity and allow boat access



diameter are present, mowing is an option, but it will not affect root systems. Fall mowing followed by flooding throughout the next growing season may effectively control willow saplings. This flooding should be deep enough to cover all above ground growth. In the South, drawdowns, should occur after seed dispersal to confine the establishment of these species to narrower zones of the site.

In years when disking is carried out to regress to early successional stages, or if food plots are desired, several species may be planted that will provide food for waterfowl. Japanese millet, smartweed, browntop millet, and corn are some of the better plantings. In some settings, prescribed burning and livestock grazing can be carried out to favor desirable plants and growth stages or suppress undesirables. Plant communities may be burned off to provide young succulent regrowth for geese and subsequent grazing by livestock to extend the young growth stages. In marshes dominated by giant cutgrass, common reed, and maidencane, periodic moderate to heavy controlled grazing can reduce these plants and favor better seed-producing annuals.

(c) Bottomland hardwood management

Bottomland hardwoods may involve long-term management to achieve desired functions and values (fig. 13-31). In the first few years after reforestation, controlling weeds by disking, mowing, or use of herbicides may speed up the growth of seedlings but benefits will seldom justify the cost. Post-planting weed control may be most critical where a heavy cover of large grasses, such as Johnson grass, or woody vines develops. Consideration should be given to negative effects on wildlife that would use the weeds as food and cover before control measures are implemented. To minimize these impacts, use control measures only if necessary. If wildfire is a danger, create a firelane

Figure 13-31 Bottomland hardwoods require many years to achieve desired functions and values

around the site annually in early fall. Fertilization may increase growth of some species on old fields or disturbed sites but may not be cost effective from a timber production standpoint. Soils should be tested for nitrogen and phosphorus. It may be better to fertilize in the third or fourth growing season when sufficient root mass is available to compete with grasses and weeds.

Very little can be done to protect seedlings from animal predation. Fencing can control domestic livestock, and good site preparation should reduce rodent populations. Only where large populations of beaver or nutria are a problem can protection of individual seedlings be justified. Chicken wire or some other predator guard could be used, especially for cypress plantings.

(d) Greentree reservoir/moist soil unit management

A greentree reservoir is an area of bottomland hardwood that is diked and shallowly flooded during the winter tree dormancy to attract waterfowl. This manipulation of water level is designed to mimic natural bottomland hardwood flooding. Flooding must be scheduled so that tree growth or plant succession is not adversely affected. To avoid timber kill or stress, flooding should not start until October. The area must be drained between February and April, depending on the latitude. The greentree reservoir should have the capability of being drained within 1 week. In the South, continual seasonal flooding after 6 to 7 years has reduced hardwood growth rates, so every other year, the greentree reservoir should remain dry during winter. For this reason, multiple compartmentalized areas may be preferable so that at least one reservoir is flooded each winter. Flooding depths should range from 1 to 15 inches.

Timber management should provide an abundant and diverse mast crop. Preferred mast trees are water oak, willow oak, cherrybark oak, shumard oak, Nuttall oak, and laurel oak. Other good mast trees include baldcypress, blackgum, hackberry, overcup, oak, swamp white oak, sweet pecan, water tupelo, and ash. Timber management often consists of thinning and creating openings. Thinning should be done to develop better quality timber and encourage mast production through crown development. Thinning can be accomplished by commercial harvesting (timber sales at 10 to 15 years), hand cutting (e.g. for firewood), tree girdling, or herbicide iroection. Some dead trees should be left standing to provide nesting sites for wood ducks and other cavity nesting wildlife.

The following considerations should be addressed when managing timber for wildlife:

- To optimize mast production, maintain a basal area of 80 square feet of desirable species per acre. Oaks should occupy from 40 to 60 square feet.
- Maintain a variety of mast producers to ensure acceptable quantities of mast each year.
- Remove or kill low value trees that provide little or no mast.
- Maintain a good distribution of desirable mast producers from seedlings through middle age pole timber to older saw timber. Optimum mast production comes from trees with a diameter at breast height of from 14 to 30 inches. A good supply of middle-aged trees will ensure sustained production.
- Create or retain large den trees and snags for nesting wildlife.

Clearings can be created in order to provide duck foods, such as smartweed, in years when mast crops may fail. Trees on the edge of openings will also have good crown development. Clearings should range from a quarter acre to 5 acres in size. They may be planted to Japanese millet, browntop millet, corn, grain sorghum, or soybeans. State baiting laws should be explained to the landowner when food plots are to be established.

650.1307 References

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Appendix A

Wetland planning checklist

1. What functions will be addressed at this restored or built wetland?
   ________education and research
   ________erosion control
   ________fish and shellfish habitat
   ________flood conveyance
   ________flood storage
   ________food production
   ________historic, cultural, and archaeological resources
   ________open space and aesthetic values
   ________recreation
   ________sediment control
   ________threatened, rare, endangered species habitat
   ________timber production
   ________water quality
   ________water supply
   ________wildlife habitat
   ________other

2. Have the following baseline data needs been addressed:

   (a) soils? .... yes —— no———

   (b) water budget? .... yes —— no———

   (c) water quality? .... yes —— no———

   (d) existing vegetation? .... yes —— no———

   (e) existing fish and wildlife? .... yes —— no———

   (f) landscape context? .... yes —— no———

   (g) wetland complex? .... yes —— no———

   (h) aesthetic quality? .... yes —— no———

   (i) other needs? .... yes —— no———

3. Are there limiting factors and constraints to restoring, enhancing, or creating the wetlands? .... yes —— no———

List limitations and constraints ____

____

____

4. Are there related opportunities? .... yes —— no———

List related opportunities ____

____

____

5. Has landuser made decisions and examined alternatives for the planned wetland? .... yes —— no———

Are structures needed to restore or enhance the wetland and meet objectives? .... yes —— no———

Can natural colonization of vegetation occur at the wetland? ....

(a) Is there an acceptable seedbank in the existing soil on site? .... yes —— no———

(b) Are there available plant material sources from nearby - or adjacent wetlands that will be transported to the site by wind, waves, currents, or animals? .... yes —— no———

(c) Will the wetland be built on non-hydric soil where seedbanks and other plant materials do not exist? .... yes —— no———

8. Will planting be required to meet wetland objectives? .... yes —— no———

(a) Will wind and wave actions cause moderate- to high-wave energy conditions? .... yes —— no———

(b) Do you need to bypass early successional stages of wetland establishment and hasten development? .... yes —— no———

(c) Are conditions suitable for application of soil-bioengineering planting methods? .... yes —— no———

(d) Will there be a problem of invading nuisance plant species that will compete with desired plant species? .... yes —— no———

(e) Will selected plant species be compatible with surrounding landscape? .... yes —— no———

(f) Are vegetated buffers, transition zones, or fences needed to protect the establishing wetland from human disturbance, excess sedimentation, pollutants, and/or intensive grazing pressures? .... yes —— no———

9. Will the desired plant species adapt to wetland site conditions and the selected location? .... yes —— no———

(a) Will they adapt to expected water depths, flood frequencies, fluctuating water levels? .... yes —— no———

(b) Will they adapt to expected water quality, salinity, acidity, alkalinity? .... yes —— no———

(c) Will they adapt to high velocity conditions? .... yes —— no———

(d) Will they adapt to standing water conditions? .... yes —— no———

(e) Are they compatible with planned landscape
features, aesthetics, and other functions? .... yes —— no———

10. Is there an adequate water supply for the wetland? .... yes —— no———

(a) Is too much water available, requiring a water control structure to
prevent the wetland from drowning? .... yes —— no———

(b) Are water rights assured? .... yes —— no———

(c) Are there existing water quality problems that may limit the success of wetland restoration or enhancement
activities? .... yes —— no———

11. Will soil amendments (fertilizers, lime, microbial enhancers) and mulch be required
for adequate plant establishment? .... yes —— no———

(a) Are substrate materials generally infertile cobble, gravel, or sand? .... yes —— no———

(b) Are substrate materials generally fertile clayey, silty, and loamy textures? .... yes —— no———

(c) Have soil analyses been taken to determine soil .... yes —— no———
amendment needs?

12. Are plant materials of desired species available and of good quality? .... yes —— no———

(a) Can enough seeds, transplants, and other propagules of appropriate size be obtained at the appropriate
time for wetland planting? .... yes —— no———

(b) Will handling, storing, and stockpiling of plant materials be necessary
before the wetland is completed? .... yes —— no———

(c) Are plant materials costs within budget? .... yes —— no———

(d) Are adapted plant materials released by NRCS and available from commercial sources? .. yes —— no———

13. Has the landuser been consulted about:

(a) Cropping/herbicide history? .... yes —— no———

(b) Current and past land uses? .... yes —— no———

(c) Ability to carry out engineering work including avoiding compacting of soils in areas not to be disturbed? .... yes —— no———

(d) Ability to carry out planting work? .... yes —— no———

(e) Willingness to conduct simple monitoring of wetland progress? .... yes —— no———

(f) Willingness to carry out mid-course corrections and active wetland management? .... yes —— no———

(g) Landscape context? .... yes —— no———

(h)Wetland complex? .... yes —— no———

(i) Management .... yes —— no———

14. Has a conservation plan been developed and decisions been documented ? .... yes —— no———

15. Has landowner been advised about needed permits (e.g. 404 perrnit)? .... yes —— no———

Site visit checklist

Observer ______________________ Date ______________________

Wetland name and location ______________________

Check all items appropriate to the wetland site being visited. Some items may not apply to a restored, enhanced, or created wetlands.

1. Does the wetland still address the original project objectives? .... yes —— no——

2. Has the wetland visually changed since your last site visit? .... yes —— no——

(a) Take site photograph(s) from fixed observation points established prior to site construction.

(b) Note physical, environmental, structural changes that have occurred:

____

____

____

3. Collect baseline (long-term monitoring) data? .... yes —— no——

(a) Soils physical and/or chemical changes? .... yes —— no——

(b) Water budget/hydrology changes? .... yes —— no——

(c) Water quality changes? .... yes —— no——

(d) Survival of planted species? .... yes —— no——

estimate percent survival
estimate percent plant cover
estimate general health and vigor of stand

(e) Colonization by other plant species? .... yes —— no——

note desirable plant species
note exotic or nuisance species
note extent of invasion (impact on planted stands)

(f) Fish and wildlife use of site? .... yes —— no——

(g) Surrounding land use changes? .... yes —— no——

4. Limitations, constraints, need for mid-course correction?

5. Remarks, comments, and site documentation

Glossary

Aerobic —A situation in which molecular oxygen is present in the environment

Aesthetic quality— The relative desirability of a landscape as determined by the impression made on the mind and the meaning given to this impression.

Anaerobic— A situation in which molecular oxygen is absent from the environment.

Banquette —An embankment at the toe of the land side of a levee, constructed to protect the levee from sliding when saturated with water.

Bedload —The part of the total stream load that is moved on or immediately above the stream bed, such as the larger or heavier particles (boulders, pebbles, gravel) transported by traction or saltation along the bottom; the part of the load that is not continuously in suspension or solution.

Biologicil diversity —Refers to the sum of all species of plants and animals. An ecosystem is generally considered healthy when it supports the maximum biological diversity known to be associated with it. In addition, biological diversity also refers to the genetic diversity found within individuals and populations of species and the diversity of ecosystems within the landscape.

Biomass —The total mass or amount of living organisms in a particular area or volume.

Connectivity— A measure of how connected or spatially continuous a corridor or matrix is. Network connectivity is the degree to which all nodes in a system are linked by corridors.

Depression— Basin in the landscape created by forces such as glaciation or wind.

Detritus—Any accumulation of disintegrated material or debris.

Dispersive clays—Clays that are usually high in absorbed sodium and that disperse or deflocculate easily and rapidly in water of low salt content.

Early successional stage—One of the primary steps in a continuum leading to a mature biological community.

Ecological community—An assemblage of species of a particular time and place.

Ecosystem—A functional system which includes the organisms of a natural community together with their environment. Derived from ecological system.

Ecotone—A relatively narrow overlap zone between two ecological communities.

Emergent —Wetlands dominated by erect, rooted, herbaceous (nonwoody) plants, excluding mosses and lichens.

Eutrophication—Process by which a lake or pond becomes rich in plant nutrient minerals and organisms but deficient in oxygen.

Faunal—Describing animals of a specifidd region or time.

Fetch—The open area and distance across a body of water in which wind can exert energy on waves to increase their strength of impact on the shoreline.

Geomorphology —The science dealing with the nature and origin of the earth's topographic features.

Geotextile— Any permeable textile material used with foundations, soil, rock, or other geotechnical material as an integral part of a man-made project, structure, or system.

Gleyed— Soils with bluish, greenish, or grayish colors resulting from saturation. Indicates a hydric soil.

Habitat fragmentation— The fragmentation of a large area of habitat into isolated patches that are not linked through corridors.

Hydric soil— Soils that are saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions.

Hydroperiod —The seasonal variability of inflow, outflow and storage of water in a wetland.

Landscape—A heterogeneous land area composed of a cluster of interacting ecosystems that are repeated in similar form throughout.

Landscape ecology —A study of the structure, function, and change in a heterogeneous land area composed of interacting ecosystems.

Landscape patterns —Arrangement of parts, elements, or details of the landscape that suggests a design of natural or human origin.

Landscape structure —The distribution of energy, materials, and species in relation to the sizes, shapes, numbers, kinds, and configuration of landscape elements or ecosystems.

Macrophytes —A megascopic plant, especially in an aquatic environment.

Microbes —Microscopic organisms.

Monostand —Existence of only one species on a site.

Mottle —Soil marked with blotches, streaks, or spots of bright red and orange indicating the presence of a high water table.

Photosynthesis —The biological synthesis of chemical compounds in the presence of light.

Phreatic line —The uppermost level at which flowing water emerges.

Propagule— Any piece of plant material that will form a new plant.

Rhizosphere —The aerobic environment surrounding root hairs of hydrophytes.

Seedbank— Residual seeds, tubers, or propagules; in or on the soil.

Soil bioengineering —The integrated use of live vegetative cuttings, independently or in combination with engineering structures, to support earth masses, prevent shallow slope failure, and reduce erosion.

Soil texture— The physical nature of soil according to the relative proportions of sand, clay, and silt.

Substrate —The foundation upon which things exist such as the soil which is the foundation for plants.

Substrate anoxia —Total deprivation of oxygen in the substrate.

Tuber— A short, thickened, fleshy part of an underground stem.

Water budget —An accounting of the Mow to, outflow from, and storage in a hydrologic unit.

Wetland —Complex The aggregation of wetlands and associated ecological features (e.g., corridors, uplands, buffers, etc.) within the landscape.