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Wetland Restoration & Enhancement Planning

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Chapter 13 Wetland Restoration, Enhancement, or Creation

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Preface

Chapter 13, Wetland Restoration, Enhancement, or Creation is one of the 19 chapters of the U. S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) National Engineering Handbook (NEH), Part 650. This chapter is designated Engineering Field Handbook (EFH), Part 650.13. Other chapters that are pertinent to and should be referenced in use with chapter 13 are:

Part 650.01 Engineering Surveys
Part 650.02 Estimating Runoff
Part 650.03 Hydraulics
Part 650.04 Elementary Soils Engineering
Part 650.05 Preparation of Engineering Plans
Part 650.06 Structures
Part 650.07 Grassed Waterways and Outlets
Part 650.08 Terraces
Part 650.09 Diversions
Part 650.10 Gully Treatment
Part 650.11 Ponds and Reservoirs
Part 650.12 Springs and Wells
Part 650.14 Drainage
Part 650.15 Irrigation
Part 650.16 Streambank and Shoreline Protection
Part 650.17 Construction and Construction Materials
Part 650.18 Soil Bioengineering for Upland Slope Protection and Erosion Reduction
Part 650.19 Hydrology Tools for Wetland Determination

Part 650.13 was last revised in May 1997. This revision was done to incorporate significant advances in the science and practice of wetland restoration, enhancement, and creation.

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650.1300 Introduction

(a) Purpose and scope

The planning, design, implementation, and monitoring of wetland restoration, enhancement, or creation project requires a multidisciplinary approach involving the disciplines of engineering, biology, geology, and soil science, among others. The scope of this chapter has been expanded beyond the traditional National Engineering Handbook (NEH), Engineering Field Handbook (EFH) focus to reflect this approach. Included in the scope is the science of wetlands and tools to assess wetland function. Wetlands, for the purpose of this chapter, are defined as areas that have anaerobic soil conditions due to the presence of water, at or near the surface for a sufficient duration to support wetland vegetation. This chapter is intended to provide field personnel with guidance in restoring, enhancing, or creating wetlands. The material included is intended to be used with the policy contained in the Electronic Field Office Technical Guide (eFOTG).

The scope of this chapter does not include the delineation of wetlands for the purpose of the National Food Security Act Manual (NFSAM). Guidance on engineering hydrology for wetland delineation can be found in the EFH650.19, Hydrology Tools for Wetland Determination. The scope also does not include wetland determinations in accordance with Section 404 of the Clean Water Act. The U.S. Army Corps of Engineers (USACE) 1987 Manual (Technical Report Y–87–1, Wetlands Delineation Manual, should be referenced for this guidance when dealing with National Environmental Policy Act (NEPA) and wetland conservation policy issues.

Also not included in the scope of this chapter are constructed wetlands. This treatment provides conditions that support hydrophytic vegetation and are used for the treatment of specific water pollutants. Information on constructed wetlands is available in NEH, Part 637.03, Constructed Wetlands.

(b) Background

Wetlands types vary widely throughout the United States. Many efforts have been made to classify wetlands according to factors such as geographic location, biological function, hydrologic function, and species composition. The method currently in use by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) and USACE for classification of wetlands is one that uses the three factors: geomorphic setting, water source, and hydrodynamics. Using these factors, seven broad hydrogeomorphic (HGM) classes have been defined by Brinson (1994). Using the broad framework of HGM, local and regional subclasses may be established. The hydrogeomorphic method also provides a framework for development of functional assessments based on the three HGM factors.

It is important to note that wetland vegetation and biological functions are critically important, even though they are not included in the top hierarchy of the HGM system. The HGM system requires an understanding of the relationships between biological function and the wetland's physical setting.

Planning of wetland projects should include an assessment based on HGM principles during the resource inventory phase. An HGM assessment of pre-project conditions will determine those wetland functions that are present and the current capacity of those functions. This forms the basis of a rational plan to restore functions or increase their capacity. It allows the analysis of the costs, benefits, and alternatives. The USACE is in the process of developing regional guidebooks for HGM functional assessments across the country. The available guidebooks can be assessed at *http://el.erdc.usace.army.mil/wetlands/guidebooks.html.*

This Web site also includes the USACE Technical Report WRP–DE–4, which describes the HGM approach, and Technical Report WRP–DE–9, which provides information on the development of a local HGM assessment.

(c) Definitions of wetland restoration, creation, and enhancement

Wetland restoration is defined as the rehabilitation of a degraded wetland or the reestablishment of a wetland so that soils, hydrology, vegetative community, and habitat are a close approximation of the original natural condition that existed prior to modification to the extent practicable (National Conservation Practice Standard (CPS) 657). In this definition, rehabilitation is restoring an existing, but degraded wetland back to its original condition. Reestablishment is the process of restoring a lost wetland back to its original condition.

Where conditions permit, restoration usually provides the most cost-effective improvement in wetland function, with the greatest increase of function of the most variables. In some cases, the original hydrologic factors that created the wetland's timing, duration, and depth of water no longer exist. If other sources of water can be supplied in a manner which provides self-sustaining hydrologic conditions over the long term, the effort can be considered a restoration.

Wetland enhancement is defined as the rehabilitation or reestablishment of a degraded wetland, and/or the modification of an existing wetland, which augments specific site conditions for specific species or purposes, possibly at the expense of other functions and other species (CPS 659). An enhancement project is still in the original wetland geomorphic setting, but its functions have been altered to add additional benefit for particular species or purposes. For example, an increase in water depth **(hydrologic regime)**, duration of water presence **(hydroperiod)**, or a change in plant community from the one originally supported by the natural wetland is considered to be an enhancement. An enhancement usually requires more management and is more expensive to construct. It augments specific functions, often at the expense of other functions.

Wetland creation is defined as the creation of a wetland on a site that was historically nonwetland (CPS 658). The creation will provide wetland hydrology on a geomorphic setting that was not originally wetland. Wetland creations usually have the highest cost and management requirements. They are usually done for only one function such as providing wildlife habitat, educational opportunities, or improving the quality of water from nonpoint source runoff. A created wetland is not the same as a constructed wetland, which is built to treat point and nonpoint sources of pollution on sites which did not naturally support wetlands.

(d) 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. Among the Federal agencies that contributed to this chapter were the NRCS, USACE, U.S. Fish and Wildlife Service (USFWS), U.S. Environmental Protection Agency (EPA), USDA Forest Service (FS), Tennessee Valley Authority (TVA), and Office of Surface Mining (OSM).

650.1301 HGM wetland classes

This section covers descriptions of the seven HGM wetland types, ways in which functions are altered, and strategies for restoration or enhancement. By definition, wetland creation is not included because creations are performed outside the geomorphic setting of a wetland. Strategies for increasing function are presented in the context of restoration. Specific enhancement strategies are included when appropriate. Examples of the seven HGM wetland classes are illustrated in figure 13–1. Figure 13–2 provides schematic descriptions of the hydrodynamics of the HGM wetland types.

(a) Depressional wetland class

(1) Geomorphic setting

Depressional wetlands exist in topographic depressions which create storage basins. The depressions may have been created by water, wind, glaciation, or other processes. Wind-created depressions include playas in the High Plains and Intermountain Region of the Western United States. Glacier-formed depressions include prairie potholes common to the Upper Midwest.

(2) Dominant water source

The dominant water sources are direct precipitation, overland flow from precipitation events, and ground water discharge. In prairie potholes, ground water may be the most significant source when the drainage area of the wetland is small. In High Plains playas, surface runoff may be the dominant water source. Vernal pools in California have precipitation as the dominant water source.

(3) Hydrodynamics

The dominant direction of water movement is vertical. Vertical loss may be upward through evapotranspiration or downward through percolation. High Plains playas and California vernal pools are examples of arid region wetlands which have very little downward movement because of low permeability soils. Almost all loss is upward through evapotranspiration. In prairie potholes of the Upper Midwest and Northern Plains, downward water movement may find its way into the local ground water table or move as interflow into adjacent depressions.

Discharge depressional wetlands gain more water from ground water than they lose. The water table grades into these wetlands. The primary loss of water is through evapotranspiration. Prairie potholes commonly act as discharge wetlands. **Recharge** wetlands gain little or no ground water inflow. They receive water from surface runoff and direct precipitation. If the length of the hydroperiod and soil permeability allow, they may recharge water into the local ground water table, and ground water recharge may be a significant wetland function. In arid region playas, almost all of the water is lost through evapotranspiration. High Plains playas usually act as recharge wetlands. **Flow-through** wetlands both receive and discharge ground water. The net flow direction may change seasonally or with wet or dry years. Prairie potholes, for example, can act as discharge, recharge, or flow-through wetlands, depending on the time of the year.

(4) Loss of function

Loss of function of depressional wetlands is commonly caused by altering the water balance. Intercepting the surface inflow into the depression is an effective way of changing the wetland hydrology so that the area can be converted to farmland or other uses. In the arid High Plains, construction of storage type terraces above the low permeability wetland soils diverts the surface runoff into the more highly permeable upland soils. In more humid areas, gradient terraces or diversions, which divert the water away from the wetland into another natural outlet, will alter the wetland. Surface ditches or underground pipelines have also been used. In many areas, the local county road system has drastically altered drainage areas with the gradient of ditches and placement of culverts. Changing the land use in the wetland drainage area can alter the hydroperiod and hydrologic regime of the wetland. One of the most common conversions historically has been the conversion of rangeland to irrigated or dry land cropland. No broad statements can be made about the increase or decrease of runoff, which applies to this conversion around the country. The interrelationships between growth stages, evapotranspiration, runoff volume, hydroperiod, and wetland regime must be determined locally, and an appropriate analysis made. Other drainage strategies involve the excavation of pits in the wetland, which move the water stored in broad shallow wetland areas into smaller deeper excavations. In the Nebraska Rainwater Basin area, these pits are utilized as an irrigation water source and serve to receive tailwater from gravity irrigation systems.

(5) Restoration strategies

In the cases where alteration has been caused by onsite drainage or diversion measures, restoration can be accomplished by removing these measures. Storage type terraces can still be allowed to function for erosion control by installing a grassed waterway or pipe outlet into the wetland. Surface ditches can be filled or blocked. Sediment which has partially filled the depression from cropland erosion can be removed down to the original wetland substrate. Uplands can be revegetated to control sediment and nutrients moving into the wetland. Excavated pits can be filled with compacted soil. Figure 13–2 exhibits the hydrodynamics of both ground water induced and playa-type depressional wetlands.

(b) Riverine wetland class

(1) Geomorphic setting

Riverine wetlands exist in association with stream corridors. They were formed by fluvial processes. They may be found in the current active flood plain or on successive stream terraces that no longer receive frequent flood flows. Riverine wetland areas are considered to be integral to the function of the entire stream corridor. Their functions are interrelated, and manipulation or restoration of one corridor function will have a direct affect on the function of the remaining corridor. However, wetlands found in the active flood plain are treated somewhat differently than those found on terraces. Restoration, enhancement, or creation of riverine wetlands should be considered in the context of the stream corridor. Stream restorations should be planned using the guidance found in NEH, Part 653, Stream Corridor Restoration: Principles, Processes, and Practices. Guidance for design can be located in NEH, Part 654, Stream Restoration Design. Executive Order 11988 requires Federal agencies not to take actions that degrade flood plain functions.

Active flood plains include the portion of the corridor which is in hydrologic and hydraulic connection with the stream. In short, they still periodically receive flood flows.

Active flood plains exhibit many complex features such as oxbows, chutes, scour channels, natural levees, backwater areas, and microtopographic features. Flood plains that are no longer active (flooded during flows in excess of geomorphic bankfull discharge) may still exhibit remnant flood plain features with wetland hydrology due to surface runoff and ponding. These features can provide valuable wetland functions and should be considered for restoration. Flood plain features subject to flooding are dynamic systems and should be designed for a minimum level of management. Constructed dikes, levees, and water control structures are problematic and have the potential to hinder the natural function of the wetland. Flood plains not currently subject to periodic flooding can include constructed features for improvement of wetland functions. These features are installed for the purpose of replacing the original hydroperiod and regime caused by the stream flood hydrograph. Dikes, levees, and water control structures are more appropriate in these cases.

(2) Dominant water source and hydrodynamics

Water source and hydrodynamics for riverine systems are considered together.

(i) Surface water—The hydrology of the system is defined in terms of the stream's hydrograph. The restored stream will provide out of bank flows and/or maintain a ground water table with a frequency sufficient to support wetland hydrology. Out-of-bank flow rates are those which exceed the **geomorphic bankfull discharge, channel-forming discharge, or dominant discharge**. This discharge is that with a return period frequency from 1 to 3 years, normally, and is often equated to the 2-year peak discharge. It is also the discharge which maintains a stable channel. Guidance on determining this discharge can be found in NEH, Parts 653 and 654. Many areas of the country have regional curve reports developed that define the bankfull discharge return period and discharge rate versus drainage area. Streams that do not provide out-of-bank flows onto their active original flood plain during this discharge can, in certain cases, be restored so that flood flows again access the flood plain.

(ii) Ground water—The ground water surface of riverine wetlands may be perched on low permeability soils in the flood plain and found significantly above the stream ground water surface during baseflow. These wetlands are **episaturated**. Water sources are a combination of flood events, surface runoff from uplands and adjacent flood plain areas, and direct precipitation.

The riverine wetland ground water surface may be directly connected to the stream water surface profile. These wetlands are **endosaturated**. In high permeability flood plain soils, a change in stream water surface translates quickly to the flood plain wetland. In these cases, the stream will support wetland conditions during periods with no out-of-bank flows if the stream water surface profile is sufficiently high.

(iii) Hydraulics —The stream's hydraulic characteristics are determined by its **channel geometry**. Channel geometry parameters include bankfull width, bankfull depth, channel slope, flood plain slope, sinuousity, and the Manning's *n* value. Hydraulic analysis can be done simply by using cross-sectional data and Manning's equation, or by analysis of the stream's water surface profile along a reach using the USACE HEC–RAS program. Simple stage-discharge data for a single cross section can be obtained with the use of the WinXSPro program.

(3) Loss of function

Loss of function in riverine wetland systems is caused by channel incision, channel bank instability, flood control dikes, alteration of the flood plain surface, or other reasons.

(i) Channel incision—Riverine wetlands that have been altered due to channel incision are common throughout the country. Incision is caused by a range of activities including channel straightening, change in watershed conditions, and interruption of sediment transport. The channel's capacity has increased to the point where flooding in the riverine wetland no longer occurs or the stream supported ground water table is too low to support wetland hydrology.

(ii) Channel bank instability—These wetlands have been altered by the loss of streambank stability. The channels often have hard, immovable beds which preclude grade loss. The banks typically have eroded because of the removal of riparian wetland vegetation due to clearing, grazing, channel straightening, flow augmentation, or watershed modifications. The bank erosion process converts riparian wetland zones to active channel.

(iii) Diked or leveed streams—These wetlands have been altered by the presence of dikes adjacent to the channel, preventing flood flows from entering the flood plain. Typically, the original wetland hydrology was provided by these flood flows, and not by stream water surface profile induced ground water. Surface water from adjacent uplands is either diverted around the wetland or is transported through the flood plain, the dike, and into the channel through a conduit with a "flap gate." The flood plain may have remnant flood plain features.

(iv) Flood plain alteration—Natural flood plains exhibit a variety of morphological features that support wetlands. Abandoned channels, scour features, natural levees, chutes, and oxbows are formed and maintained by the interaction between the stream and flood plain during out of bank flows. These features are **macrotopography** features. These features are commonly erased to increase the land's productive capacity for agriculture. Surface ditches and buried drain conduits may be installed to move surface and ground water from the wetland into the stream channel.

Microtopography features are extremely valuable to riverine wetland function. They are created by surface flows, blowdown of trees, or the action of certain high shrink-swell soil types (gilagi microtopography). These features, by definition, are less than 6 inches in height or depth. These features are also commonly erased by changes of land use in the wetland.

(4) Restoration strategies

For the purpose of this discussion, the term active flood plain includes those flood plains that were active before historic stream corridor alterations, such as levee construction or channel incision.

The most comprehensive restoration is one which restores dynamic hydraulic and hydrologic connectivity of the stream to its flood plain. It must be recognized that a strict **restoration** of the stream corridor to historic conditions may be inappropriate. In many, if not most cases, the original stream watershed conditions no longer exist. Thus, the original stream hydrographs that formed the channel geometry found on old aerial photography and topographic maps would not provide long term dynamic equilibrium today. However, the channel can be provided a new geometric template under current hydrologic conditions which provides long-term stability and connectivity with its flood plain. The benefits to this approach are many. They include:

- increased diversity of wetland hydroperiod and regime
- minimum long-term maintenance of constructed features
- minimum management requirements
- natural cycling of plant communities' age and diversity
- maximum connectivity for aquatic organism passage, both laterally and longitudinally

Constructed features of the flood plain are limited to restoring or mimicking the original shape, size, and geometry of remnant flood plain features. These features include the natural levees, scour channels, abandoned oxbows, sloughs, and microtopography mentioned earlier. In the comprehensive restoration approach, these features are assumed to begin functioning dynamically after restoration and will adapt themselves in form by interaction with flood flows after the restoration is complete.

Where a comprehensive restoration of flood plain connectivity is not possible due to land ownership, economic, or other considerations, an attempt must be made to increase function by increasing flood plain hydroperiod, hydrologic regime, and connectivity, as much as possible. Partial breaching of levees, construction of flood plain features, and installation of water control structures and other measures can be accomplished. As the potential for complete dynamic restoration decreases, the required level of management and maintenance increases. Specific strategies for riverine wetland restorations based on the previous loss of function categories follows.

(i) Channel incision—There are three basic options to increase wetland function. The first concentrates on the flood plain wetland area with no attempt to restore the channel. The area must support wetland hydrology with surface runoff and ponding. Surface runoff from uplands and other flood plain areas is diverted and stored with structures to provide wetland hydrology. If water level is to be controlled, the means of control must be designed in accordance with CPS 587, Structure for Water Control.

The second alternative option is to raise the stream water surface profile by installing grade stabilization structures, decreasing the channel capacity by decreasing the width and/or depth, or both. It is critical to ensure that the upstream effects do not extend beyond the project boundary or to obtain easements for these effects. This option is most appropriate where the channel has incised in place, without channel straightening. The grade stabilization structures should be full-flow, open structures, spaced closely together to prevent excessive water surface profile drop between structures and designed in accordance with CPS 410, Grade Stabilization Structure. The drop is typically held to about 1 foot between structures. Careful attention is given to the downstream structure where the profile is returned to the incised channel. Interruption of sediment transport caused by the new structures can cause grade loss downstream of the project.

Installation of embankment dam grade stabilization structures on the stream channel should be considered an enhancement practice. Routing flows through a detention pool will alter the stream hydrograph and result in a change of HGM wetland type from riverine to depressional, with a resulting trade-off in wetland function. This installation usually results in higher operation and maintenance requirements.

The third alternative option is to perform a complete meander reconstruction of a new channel with the appropriate width, depth, slope, and sinuousity to restore horizontal connectivity with the flood plain wetlands. The services of a trained fluvial geomorphologist may be needed. Planning and design are accomplished in accordance with NEH, Parts 653 and 654.

(ii) Channel bank instability—In cases where no channel incision has occurred and wetland hydrology still exists, restoration focuses on reestablishing wetland vegetation. In many cases, livestock exclusion is all that is necessary. Soil bioengineering measures should be incorporated in accordance with CPS 580, Streambank and Shoreline Protection. Guidance can be found in NEH, Part 654.

(iii) Diked or leveed streams —A complete restoration would require removal of the dike. Often, it is cost prohibitive to completely remove the dike and properly dispose of the fill material. Usually, flood flows can be allowed onto the flood plain by breaching the dike in one or more locations. The areas of dike removal must be carefully considered. A breach at the downstream end of the diked area will allow backwater to enter the wetland and minimize the danger of high velocity floodwater flowing through the wetland. Internal wetland structures can be maintained for water level control using this approach. An additional breach at the upper end of the area will allow flood flows to pass through the system. This approach can be utilized to allow the stream system to maintain a natural dynamic wetland, with associated scour channels, natural levees, abandoned oxbows, and other flood plain features. Internal water level control structures are problematic using this approach, as they are subject to headwater flows through the flood plain.

A hydraulic analysis of the system is recommended when designing a headwater dike removal. The resulting change in the stream water surface profile at the up and downstream end of the project may create channel instability. Removal or breaching of the dike is often not possible because of land rights or off project effects. A restoration then must focus on using an alternate water source to mimic the original hydroperiod and hydrologic regime of the riverine system. Water is only available from precipitation and onsite and offsite surface runoff. Structural measures, such as dikes and water control structures, are usually required.

(iv) Altered flood plains—

Macrotopography replacement—Restoration and enhancement efforts should include replacing macrotopography features such as abandoned channels, oxbows, and scour channels. These features, as opposed to microtopography features, are greater than 6 inches in depth. Often, aerial photography and historical records can provide the location and extent of these features so they can be rebuilt to their original geometry. Otherwise, reference reaches of the same stream or similar streams can provide a template for restoration of these features. If the stream is still in hydraulic connection with the flood plain, it is important to construct flood plain features that are stable during flood flows. Figure 13–3 shows an example of macrotopography restoration in a riverine wetland.

Microtopography replacement—Microtopographic features are those that provide less than 6 inches in water depth. They experience frequent wetting and drying, and thus provide a dynamic range of habitats, both spatially and temporally, which many wetland plant and animal species depend upon. These features should be installed with varying depths, size, and spacing to provide a range of hydroperiod and hydrologic regime. Figure 13–4 shows an example of natural microtopography created by tree blowdown. Figure 13–5 shows an example of restoration of gilgai microtopography.

(c) Slope wetland class

Slope wetlands occur where there is a discharge of ground water to the land surface. (USACE WRP DE–9). This is a deceptively simple definition which requires much further explanation.

(1) Geomorphic setting

Slope wetlands can be divided into two categories. Topographic slope wetlands occur in concave convergent positions on landscapes. Stratigraphic slope wetlands occur where the landscape geology creates anisotropic conditions that focus ground water to a point of discharge.

(i) Topographic slope wetlands—Concave landscape positions occur at the head end of watershed boundaries. Thus, topographic slope wetlands may be adjacent to and converge with riverine wetland systems. The dominant water source is ground water. The concave topography focuses ground water to a single low point on the landscape. If the ground water discharge exceeds the losses due to evapotranspiration from the land surface, a flowing spring develops. These wetlands can transition into riverine or depressional systems downslope.

These wetlands typically appear in a shape dictated by the convex shape of the landscape. The upper boundary may appear with a gradual change in plant community transitioning to hydrophytic. The lower end commonly exhibits spring flow which occurs permanently, or only at the peak of the hydroperiod. As stated earlier, these wetlands are commonly the beginning of a stream channel network. They may also transition into depressional, lacustrine, or estuarine fringe wetlands. The geomorphic setting and hydrodynamics of topographic slope wetlands are illustrated in figure 13–2.

(ii) Stratigraphic slope wetlands —An anisotropic condition is one in which the vertical hydraulic conductivity and horizontal hydraulic conductivity are not equal. In most cases, the lateral conductivity is greater than the vertical. These conditions are created by a layer of low permeability soil, or rock which has a very low vertical hydraulic conductivity. These layers focus ground water flow to a point of surface outlet on the landscape. Usually, these wetlands are horizontal, shallow vertically, and have a sharp upper boundary. They lend themselves to the development of springs for use by humans or livestock. When compared to topographic slope wetlands, they usually have less vertical extent, and broader horizontal extent.

(2) Dominant water source

The dominant water source is ground water. Significant contributions may be from direct precipitation and surface runoff. It is important to note that the ground water source is direct precipitation. In some cases, the ground water recharge area of these systems can be determined from surface topography, and water budget studies can be made using precipitation and evapotranspiration data.

(3) Hydrodynamics

The dominant direction of movement is horizontal and unidirectional.

(4) Loss of function

The loss of slope wetland conditions is usually associated with the interception or sealing of the ground water source. This interception may be associated with changing land use to a cover which decreases the percolation of rainfall, such as urbanization. A change of use from rangeland to cropland may decrease the plant evapotranspiration enough to actually induce slope wetland conditions. This phenomenon occurs in "saline seeps," which are found in the northern High Plains and Intermountain Region of the United States, where rangeland has been converted to dryland wheat production. Compaction of slope wetland areas due to overgrazing may prevent water from reaching the surface. Poor grazing practices may also promote the growth of woody vegetation, which may have a higher evapotranspiration rate than the original herbaceous cover. A very common interception method is the installation of horizontal tile drains for the purpose of eliminating wetland conditions at the base of the slope adjacent to cropland. This method is especially effective in stratigraphic slope situations, where the interception can be focused directly on the confining rock layer. On flatter slopes, surface ditches have been used to intercept ground water flow and divert it elsewhere. The installation of spring developments for livestock or domestic water supply can alter wetland conditions.

(5) Restoration strategies

Restoration can be readily accomplished on sites where physical drainage measures have been installed. Removal, plugging, or filling of these tile drains or ditches is effective in restoration. On sites where watershed conditions have been changed, proper grazing management, brush control, or conservation tillage practices can reestablish wetland hydrology.

(d) Mineral soil flat wetland class

Mineral soil flat wetlands are most common on uplands between stream valleys (interfluves) and on extensive relic lake bottoms where the dominant water source is precipitation. Common hydrology analysis tools are water budget tools and scope and effect equations, when drainage systems have been installed. Mineral soil flats may transition into riverine, hillslope, and depressional wetlands.

(1) Geomorphic setting

Mineral soil flats are generally flat to very gently sloping, with few natural surface drainage features. They generally are formed in slowly permeable soils, which hold water close to the surface. They occur extensively in eastern North Dakota, South Dakota, Minnesota, Iowa, and on the coastal plain of the Southeastern United States.

(2) Dominant water source

The dominant water source is direct precipitation. They receive virtually no ground water discharge and very limited surface runoff. They commonly occur in humid climates where the evapotranspiration during the hydroperiod is much less than the rain or snowfall.

(3) Hydrodynamics

The water movement in mineral soil flats is mostly confined to vertical fluctuations. Precipitation is stored in shallow depressions on the surface until it can infiltrate into the soil. Downward percolation under the force of gravity discharges water into the water table, which is commonly perched. Upward flux caused by capillarity replaces water from the ground water (if available), which is lost through evapotranspiration.

(4) Loss of function

Vast areas of mineral flat wetlands in North America have been drained by buried tile drains or surface ditches. This physical drainage is virtually the only method of converting mineral flats to nonwetland conditions. Converting the slow discharge of these original wetlands to point discharges from ditches and pipes has eliminated much of the original nutrient cycling function of these areas. The result has been an increase in dissolved nitrogen in the rivers and tributaries of the Mississippi River Basin. The flood attenuation function has also been decreased.

The coastal plain of the Eastern and Southern United States has large mineral flat wetland areas which were once native forest or savanna. These soils have a horizon, which serves as reservoir for precipitation during the wetland hydroperiod. Conversion of land to grazing can lead to severe compaction of the surface, which prevents rainfall from percolating into the soil. The water is lost to direct runoff, preventing the maintenance of wetland conditions.

(5) Restoration strategies

Effective restoration of drained mineral soil flats is commonly done economically by partial removal or plugging of the original drainage tiles or ditches. In most cases, little increase in function is realized by complete removal.

Restoration of hydrology due to surface compaction can be accomplished with grazing practices which increase soil tilth and root development. This can include precluding grazing during the wet period of the year when soil compacts readily. Other measures include physical ripping of the area or establishing vegetative cover (forest or herbaceous).

(e) Organic soil flat wetland class

Organic soil flats are similar to mineral soil flats. However, their elevation and topography are controlled by the vertical accumulation of organic matter. They are common in the North-central, Northeastern, and Southeastern United States.

(1) Geomorphic setting

Organic flats commonly occur on flat uplands between stream valleys (interfluves). They also commonly occur in large depressions, where organic accumulation has formed a flat surface. Organic flats occur in the unique situation where biomass from dead plants builds up faster than decomposition. **Anaerobic** conditions caused by saturation slow or halt this decomposition.

(2) Dominant water source

The source of water is usually limited to direct precipitation. On the margins of organic flats in large depressions, ground water may be a significant water source.

(3) Hydrodynamics

Water movement is essentially vertical. Precipitation infiltrates into and percolates downward into the soil. Water moves out of the wetland by percolation into the ground water table and by overland flow when saturation occurs.

(4) Loss of function

Drained organic flats often provide extremely rich agricultural soils. Tile drainage, surface ditches, and bedding are frequently used to partially or completely drain these wetlands. While the carbon sequestration benefits of existing organic wetlands may be in equilibrium, drainage almost certainly causes aerobic decomposition, which releases organic carbon into the atmosphere. In addition, drained organic flat wetlands can experience **subsidence** when aerobic conditions cause a loss of organic soils. Instances of subsidence of several feet have occurred in extreme cases. Many threatened and endangered plant species exist only on these organic soils.

(5) Restoration strategies

Restoration will focus in removing the original drainage methods, similar to the treatment for mineral flats. In areas where large subsidence has occurred, the restoration of the original ground water level will result in large areas of open water where wet soil conditions occurred originally. The open water areas will not support the original wetland plant communities which provided the plant material to develop organic soils. However, any saturated conditions will halt further loss of organic soil.

(f) Lacustrine fringe wetland class

These wetlands exist in a zone between nonwetland and deepwater areas adjacent to freshwater water bodies (lakes) which are generally larger than 20 surface acres in size. On the landward side, they may transition to slope wetlands. Large prairie potholes and playa lakes can be considered to maintain lacustrine fringe wetlands along their shorelines.

(1) Geomorphic setting
The lacustrine fringe is a gently sloping transition area into the lake.

(2) Dominant water source
The dominant water source is the lake's water. The water moves into the fringe as ground water maintained by the lake level or surface overflow as the lake level rises. Additional water sources can be overland flow from uplands, direct precipitation, and ground water discharge from upland sources.

(3) Hydrodynamics
The movement of water is bidirectional and horizontal. Lake level rises move surface and ground water into the wetland, and lake level lowering causes the reverse.

(4) Loss of function
Conversion of lacustrine fringe wetlands, when done, is usually by filling with mineral soil for the purpose of increasing available land for agricultural production or development.

(5) Restoration strategies
Restoration must be accomplished by lowering the wetland surface to its flood plain original level relative to the lake level. This is expensive and is not commonly done.

(g) Estuarine fringe wetland class

(1) Geomorphic setting
Also called tidal fringe wetlands, this type exists along coasts and estuaries which are under the influence of tides. They transition into riverine wetlands as the tidal currents diminish upstream. They may also transition into slope wetlands at the horizontal boundary of the estuary.

(2) Dominant water source
The dominant water source is tidal fresh or brackish water controlled by tidal action. Additional water sources can be precipitation, streamflow, and ground water recharge.

(3) Hydrodynamics
Water movement is essentially bidirectional and horizontal as tidal action moves water inland and seaward with tidal fluctuations. The movement is bidirectional near sea level and transitions to unidirectional inland, as the dynamics are dominated by outflow from the adjacent river.

(4) Loss of function
Estuaries can be physically converted by filling, or conversion can be initiated by altering the interaction between freshwater, saltwater, and wetland vegetation. In the extensive estuarine wetlands of Louisiana and Mississippi, interior marshes are freshwater and maintain their base level by the build-up of organic soil due to the decomposition of freshwater plants. As channels for boat access are cut through these freshwater marshes, tides can push saltwater deep into these freshwater areas and cause the plants to die. Loss of this plant cover leads to loss of organic build-up and leaves the original soils exposed to erosion.

Saltwater marshes receive seawater by the direct action of tidal flows. These areas are commonly altered by the installation of dikes, which prevent high tide stages from accessing the wetland.

In both fresh and saltwater marshes, tidal flows enter and leave the wetland through discrete tidal channels. The natural size, shape, and slope of these channels were determined by the complex interactions between volume of flow, tide cycles, and interaction with freshwater from inland. Freshwater marsh wetland improvement is usually concerned with blocking manmade channels.

(5) Restoration strategies
In the case of saltwater intrusion into freshwater marshes, restoration can be accomplished effectively by blocking channels which allow tidal saltwater. Exposed eroding soils, whether organic or mineral, can be revegetated to prevent further loss. If subsidence due to decomposition of organic soil has occurred, the restored area will have a deeper hydrologic regime than the original. Selection of plant species must take this into account.

Saltwater marshes with dikes can be restored by careful removal of dike sections and the re-creation or restoration of an inlet channel. Saltwater marsh improvement is especially complex because it focuses on the analysis of the inlet channel dynamics. A detailed discussion of saltwater marsh tidal flows is found in 650.1304(a)(3)(i).

Figure 13–1 HGM wetland types

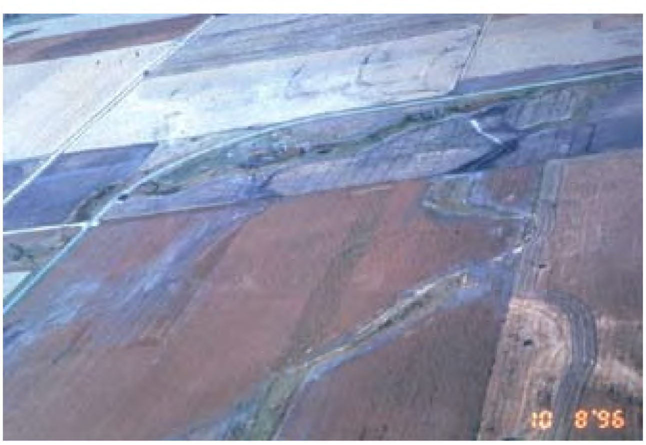
(a) Concave slope wetland

(b) Concave slope wetland— Idaho

(c) Stratigraphic slope wetland— Kansas

(d) Depressional wetland—California vernal pool

(e) Mineral soil flat—Minnesota



(f) Riverine—Colorado

Figure 13–1 HGM wetland types—Continued

(g) Depressional—High Plains playa—Texas

(Photo by Dr. Loren Smith)

(h) Depressional—Prairie potholes—South Dakota

(i) Estuarine fringe wetland —Connecticut

(j) Riverine wetlands—Tennessee

Figure 13–1 HGM wetland types—Continued

(k) Estuarine fringe—Oregon

(l) Lacustrine fringe wetland—Wyoming

Figure 13–2 Hydrodynamics of HGM wetland classes

(a) Depressional wetland with perched water table—playas

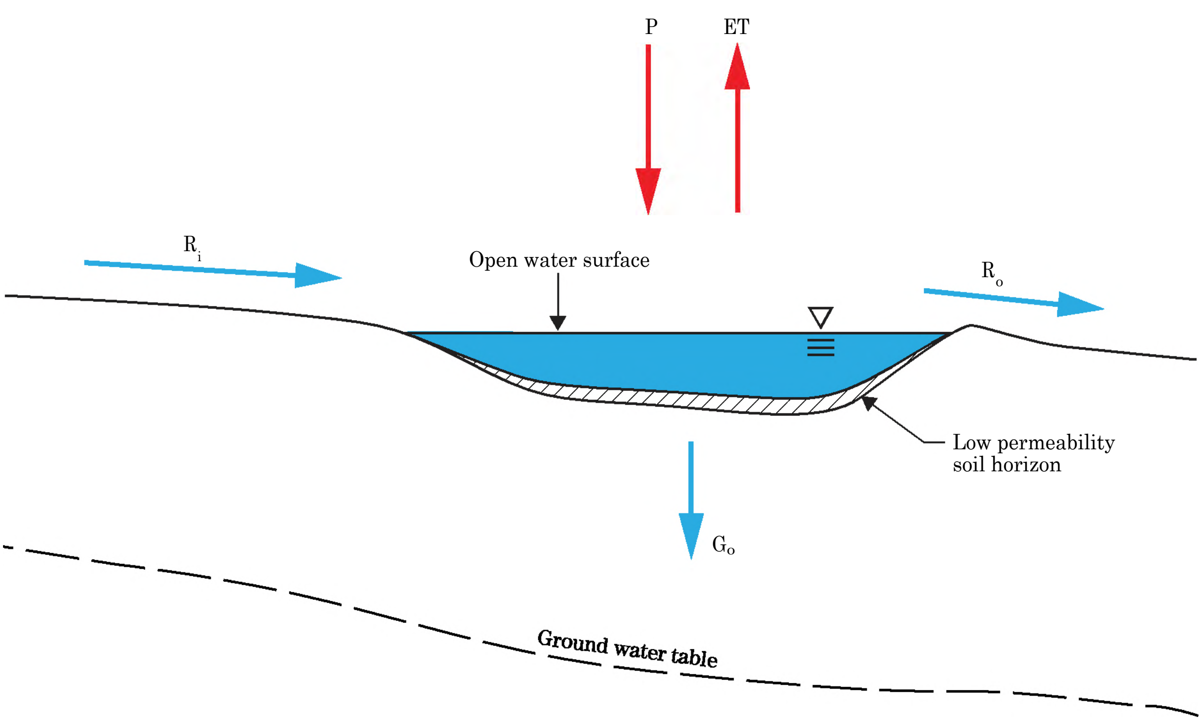


Figure 13–2 Hydrodynamics of HGM wetland classes—Continued

(b) Depressional wetland with ground water influence —prairie potholes

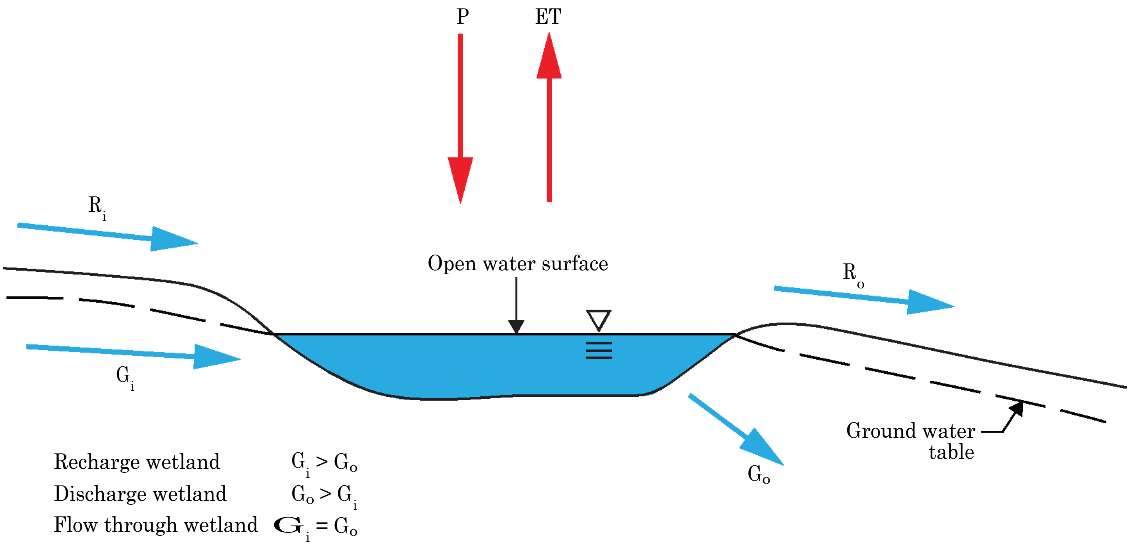


Figure 13–2 Hydrodynamics of HGM wetland classes—Continued

(c) Topographic slope wetland —plan view

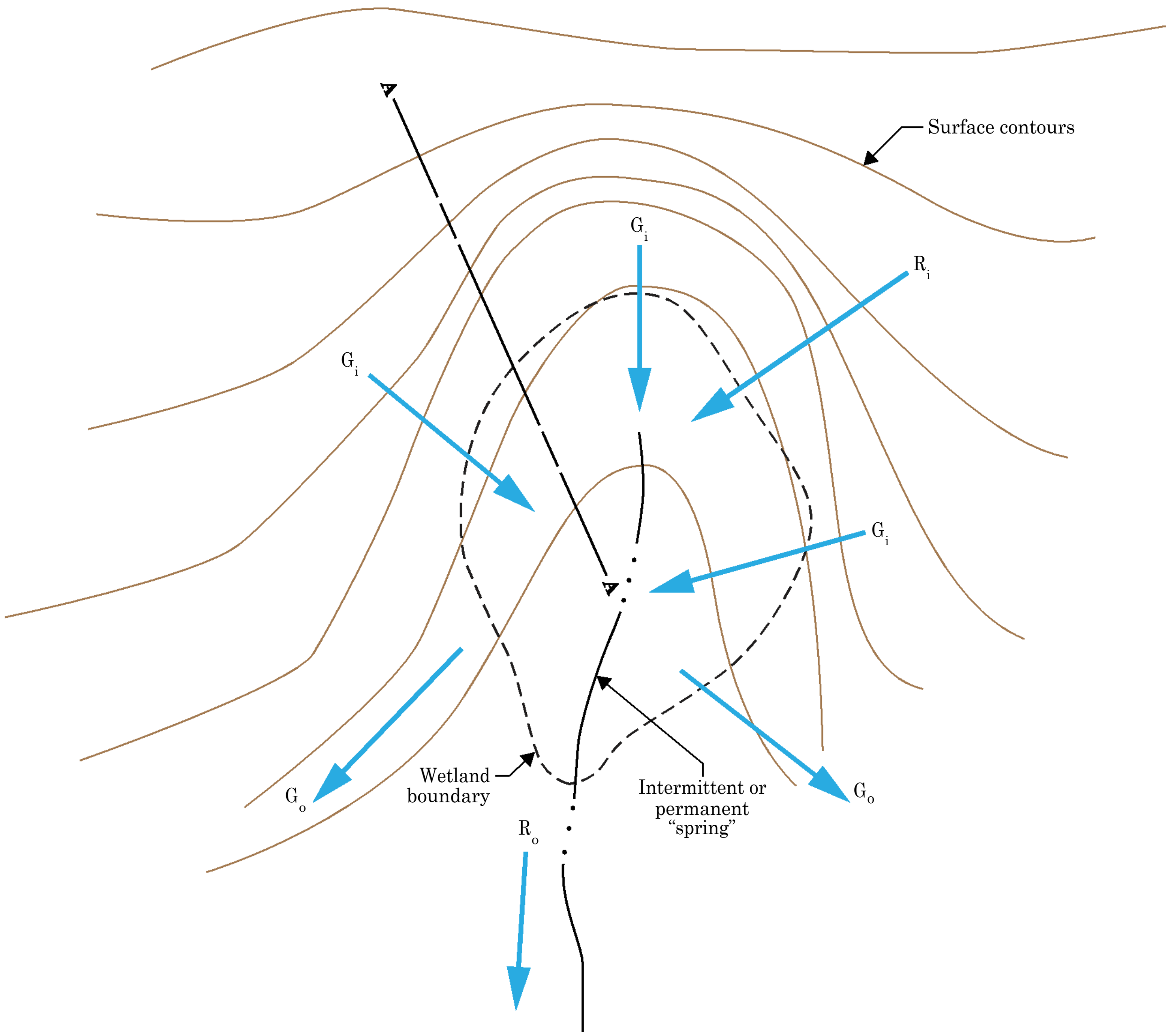
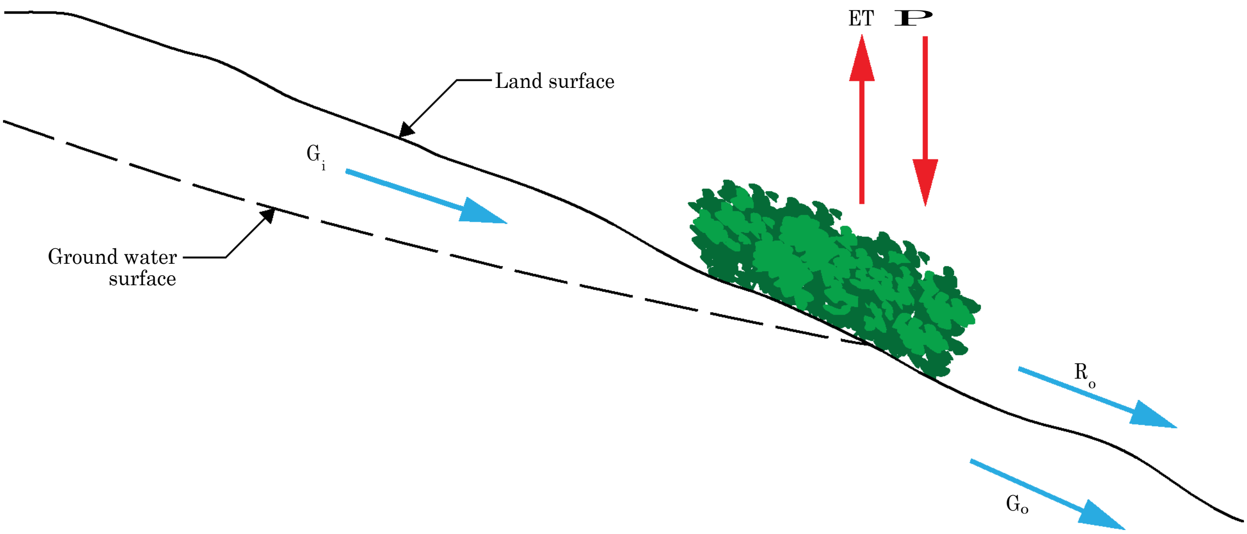


Figure 13–2 Hydrodynamics of HGM wetland classes—Continued

(d) Topographic slope wetland—cross section



(e) Stratigraphic slope wetland—plan view

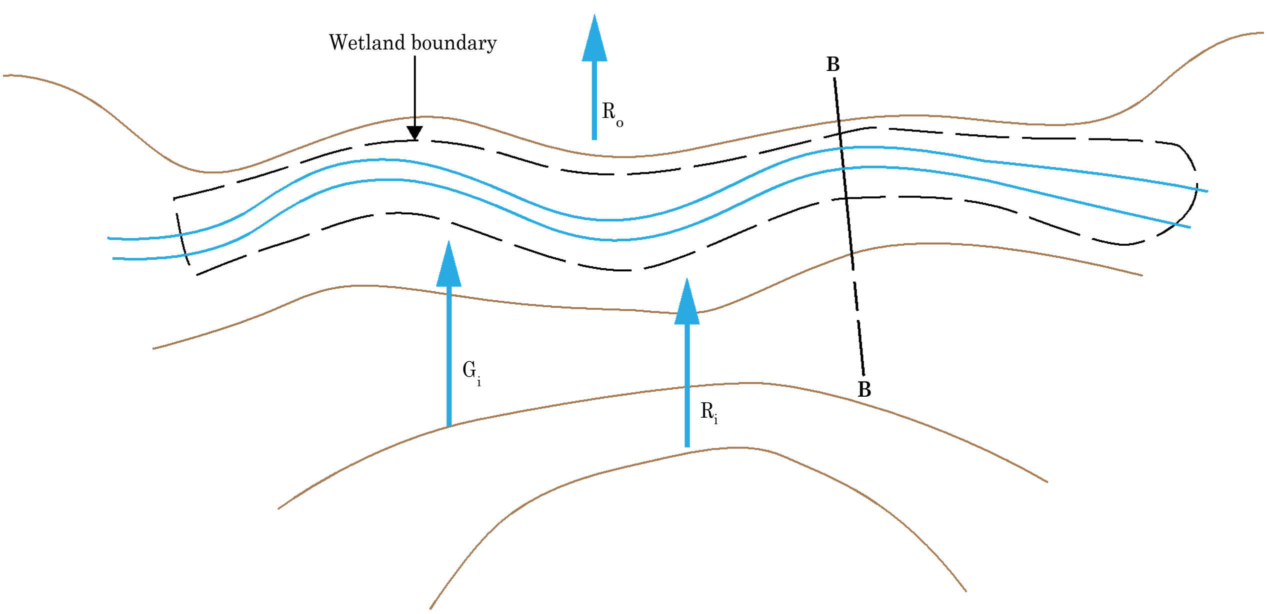
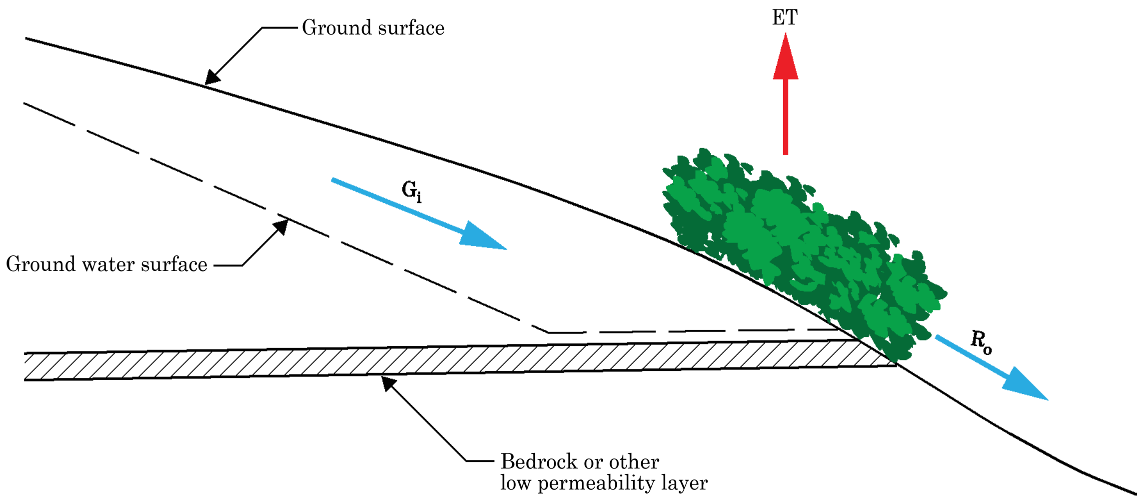


Figure 13–2 Hydrodynamics of HGM wetland classes—Continued

(f) Stratigraphic slope wetland—cross section



(g) Mineral soil flat wetland

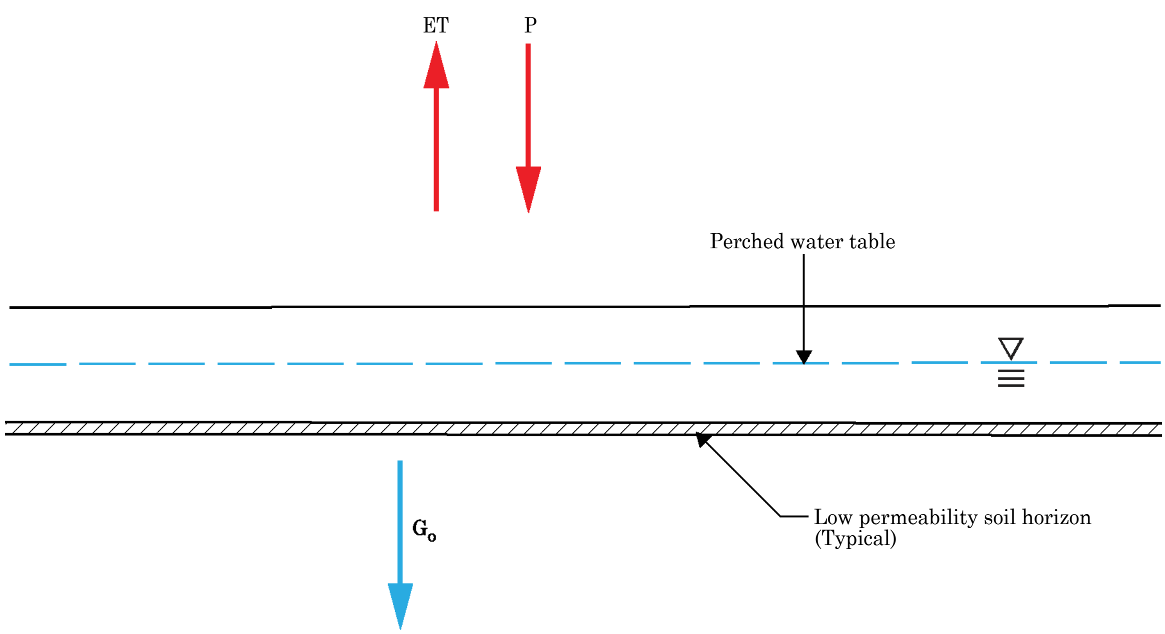


Figure 13–3 Restoration of flood plain macrotopography

Figure 13–4 Microtopography feature created by a blown

Figure 13–5 Restoration of microtopography on gilgai soils on a riverine wetland

650.1302 Wetland processes and characteristics

(a) Physical processes

As stated in the previous section, the fundamental physical factors that control wetland functions are geomorphic setting, water source, and hydrodynamics. Each of these three factors must be defined in the planning stage. Decisions can then be made regarding the need and appropriateness of restoring, enhancing, or creating the functions of these factors.

(1) Geomorphic setting

Geomorphic setting is the landform of a wetland, the geologic process which created it, and its position on the landscape. The geomorphic setting defines the seven classes in the HGM system. Planning for restoration should focus especially on working within this setting. Wetland enhancement and creation projects can be planned to mimic features of a particular setting to improve certain functions.

Geomorphic setting can be dynamic in nature. For instance, a riverine wetland on a broad flood plain flat can be restored by excavation to create an original abandoned oxbow feature. However, the original riverine setting had a shallow stream that flooded every other year. If the channel is now incised to the point where it floods only every 10 years, the geomorphic setting of the feature has changed, with subsequent changes in its hydrology. Another example is a topographic slope wetland where erosion has advanced a channel through the elevation where ground water reaches the surface. The hillslope wetland may move laterally away from the new channel, and the original area is now evolving into a riverine HGM type.

(2) Dominant water source

A wetland's hydroperiod refers to the timing, duration, and depth of saturation and inundation. This hydroperiod is controlled by a dominant source of water. Water sources include direct precipitation, surface runoff, ground water inflow, stream flood flows, lake overflow, and tidal fluctuations. Most wetlands also have one or more secondary water sources. Restorations should focus on reestablishing this dominant water source. If an enhancement is done with water sources which were not the original dominant water source, the hydroperiod may be changed. With different water sources, water chemistry and temperature differences may also influence plant, animal, and microbial communities, with effects on wetland functions.

For example, a depressional wetland may have originally been supplied with water from ground water inflow, providing a long-term steady water level in the wetland. If the restoration plan is to supply water by diverting more surface runoff, the wetland will show more fluctuation, more extremes between wet and dry periods, and will receive water somewhat earlier than originally.

(3) Hydrodynamics

Hydrodynamics refers to the direction of flow and strength of water movement within the wetland. These factors have a profound effect on the species and composition of vegetation, the morphology and composition of wetland soils, and the quality of the water in the wetland. Directions are referred as vertical or horizontal and unidirectional or bidirectional. In addition, wetlands are defined as discharge or recharge wetlands with respect to ground water flow. Project planning should define the wetlands current and restored hydrodynamics.

(4) Common physical considerations

(i) Sedimentation in depressional wetlands—Sedimentation is a temporary condition which typically results when watershed conditions change to deliver sediment to a wetland faster that the rate of hydric soil formation. The wetland suffers a loss of capacity and a shortened hydroperiod. In addition, sediment changes the physical and chemical characteristics of the wetland soil, with corresponding changes to the vegetation and habitat characteristics. Restoration can be accomplished by intercepting the sediment with soil conservation practices on the watershed, physically removing the sediment down to the original hydric soil layer, increasing the depth of the depression with water control structures, or combinations of these practices. Care should be exercised when removing sediment. The original surface layer of wetland soils is usually rich in organic material and other nutrients. Excavation down to a dense low permeability soil layer may remove this surface layer, but with a negative impact on the wetlands ability to establish a healthy plant and animal community.

(ii) Aerobic decomposition of organic soils—Organic soils form when anaerobic conditions prohibit the breakdown of organic matter at the same rate as its formation. Large amounts of organic carbon exist in organic soil flat wetlands. When drained, aerobic breakdown of these soils releases large amounts of carbon dioxide into the atmosphere. In these cases, the saturated condition must be restored to its original condition. Increasing the depth of inundation beyond its original level may prevent the growth of new plant material, thus ceasing or minimizing the carbon sequestration attributes of the wetland.

(iii) Stream modification in riverine systems—Modifications to a stream's channel geometry, hydraulic characteristics, and flow have direct affects to the adjacent riverine wetland through changes to the volume, timing, and duration of the water supply. Water is delivered to riverine systems as both surface and ground water. Changes to the stream's cross section, location, or flows can affect both the ground water and surface water delivery.

(b) Chemical processes

(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 oxidized ions (such as NO_3^-, Mn^{+4}, Fe^{+3}, $SO_4^=$) gain additional electrons and are changed to reduced 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 may be the most limiting nutrient for plant growth in estuarian systems, 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 (Fe^{+2}), and manganese (Mn^{+2}) 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 ($S^{=}$), it can form hydrogen sulfide gas (H_2S) 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, although in extremely high concentrations has been found to be soluble. In freshwater wetlands, it is the most limiting nutrient for plant growth, thus 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.

(7) Salinity

Depressional wetlands with ground water influence are either “recharge,” “discharge,” or “flow-through” wetlands. Recharge wetlands gain more ground water than they lose. The difference is made up with evapotranspiration and surface outflow. Discharge wetlands lose more ground water than they gain. Their dominant water sources are surface runoff and precipitation. Flow-through wetlands have a rough net balance in ground water inflow and outflow. If there are sufficient salts available in the geologic substrate, recharge wetlands tend to be more saline than discharge wetlands if their dominant loss of water is evapotranspiration. Water uptake by plants and surface evapotranspiration leaves mineral salts behind. Discharge wetlands, which receive surface water, tend to have lower salt content. In some cases, changing the wetland’s hydrodynamics by increasing or decreasing the surface water supply can alter the salinity level. The surface water component of the water budget can be changed by diverting surface water, changing the watershed vegetation or management, or other methods.

Large areas of the United States have a surface geology dominated by marine shales, which hold sodium in the rock matrix by electrochemical attraction. As water moves downward into these shales, the highly soluble sodium ions move with the water, and the low permeability of the shales forces this solution to move laterally to a point of discharge on the land surface. As water evaporates, the sodium ions recombine with sulphate or chloride ions to leave salts behind on the surface. These areas are called “saline seeps.” Changes in vegetative cover in the ground water recharge area can have a very direct effect on the amount of water available to these seeps.

(c) Biological processes

(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, emergent, submergent, herbaceous, or woody. Vegetation creates structure within the wetland (vegetation strata and aquatic zones) that serve as shelter and breeding sites for animals (fig. 13–6). Wetland plants also transport oxygen from the atmosphere, through the stem, and into the roots that grow in anaerobic conditions. Wetland plants, along with microbes, are the most basic and critical components in wetlands. Plants use solar energy to produce organic carbon, which serves as the food source for the entire biotic community, including animals and microbes. Radial oxygen loss from the roots creates an oxidized zone in the soil immediately surrounding them. The value of microbes to vegetation is described. Wetland vegetation also traps sediment and removes nutrients and pollutants from the water column and soil. Wetland plants produce more biomass (stored carbon) per acre than any other species group and export huge quantities of detritus to aquatic systems, providing direct benefits for food web support.

(3) Animals

Wetlands provide water, food, shelter, breeding, and nesting sites for many animals including many rare and declining, threatened, and endangered species. Diverse assemblages of micro and macro invertebrates, fish, amphibians, reptiles, birds, and mammals are found in, and are dependant upon, wetland systems. As individuals, animals influence small scale processes within wetlands, whereas a population of individuals may exact significant, large-scale influences on wetland dynamics and function. In addition to wetland dependant animals, many species typically not recognized as wetland residents spend some part of their life cycle or fulfill daily requirements within wetlands.

Figure 13–6 Wetland vegetation has a role in many wetland functions (Marsh Pepper)

650.1303 Pre-implementation wetland planning

The nine steps of planning include the implementation phase, of which design and monitoring are a part. This section includes the seven steps of the process up to implementation.

(a) Planning step 1—Define the problem

The first step in wetland planning which is often overlooked is to define the problem. A helpful tool is a functional assessment model for the HGM wetland type. This model will have a list of appropriate functions for this HGM type. The problem definition then becomes an exercise of determining which of the current functions is lacking or needs improvement. Use of this tool can prevent the misallocation of time and resources in implementing a project which cannot perform properly.

(b) Planning step 2—Determine objectives

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 in the local functional assessment. Examples of wetland functions are 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.

Table 13–1 Common wetland functions and processes

Function	Description	Function interaction	Planning/design considerations
Physical processes			
Dynamic surface water storage	The capacity of a wetland to detain moving water from surface runoff for a short duration (flood routing)	In addition to downstream flood reduction, this function can improve water quality through retention of sediments, improved nutrient cycling, and improved quality of wildlife habitat	In riverine systems, planning for increased floodwater storage must be done in the context of the stream corridor. Vegetation, channel geometry, sediment transport, and planned structural components interact during surface runoff events. In depressional systems, floodwater storage must account for sediment accumulation
Long-term surface water storage	The capacity of a wetland to retain surface water for long durations	Long-term storage increases the wetland hydroperiod, with consequent benefits to vegetation, habitat, and nutrient cycling	Water storage can be improved by changing other factors in the water budget such as hydraulic conductivity, volume of inflow, plant transpiration, or available wetland storage volume. Operating a wetland at its maximum depth past its hydroperiod decreases available surface water storage
Subsurface storage of water	The availability of storage for water beneath the wetland surface	Subsurface water storage increases the hydroperiod, provides water to plants through dry periods, and increases the potential for anaerobic nutrient cycling	Over compaction of wetland substrate or removal of highly organic, low-density sediments can decrease the available pore space for storage of water. Maintaining a wetland at its maximum storage capacity outside the hydroperiod decreases available subsurface water storage
Chemical processes			
Removal of imported elements and compounds	A wetland's ability to remove delivered nutrients, elements and compounds, and contaminants	The wetland serves as interceptor of material delivered from incoming water sources. The result can be an increase in water quality in the wetland, as well as in water delivered from the wetland, with consequent improvement in vegetation and habitat both onsite and offsite	Wetland restoration, enhancement, or creation should not be used to treat specific point source pollutants. Use the Constructed Wetland Conservation Practice Standard in these cases. Nonpoint source runoff treatment should consider the need to remove a build-up of phosphorous or other mineral elements by plant harvesting or sediment removal

Table 13–1 Common wetland functions and processes—Continued

Function	Description	Function interaction	Planning/design considerations
Chemical processes—Continued			
Retention of particulates	The deposition and retention of inorganic and organic particulates from the water column, primarily through physical processes	Sediment and organic solids can be suspended by water entering the wetland that has sufficient tractive stress to entrain these materials. Velocity reduction due to static surface water in the wetland, or dense vegetation causes deposition. The quality of water delivered from the wetland is improved, and deposition is prevented from impairing downstream or offsite areas	The long-term accumulation of sediment must be considered for its effects on wetland function. Riverine restorations can be designed to cycle sediment into and out of the stream corridor, if planned to function dynamically. Vegetative functions may suffer because of sediment. Watershed treatment of upland drainage areas should be considered for sediment reduction. Depressional wetlands that capture sediment can be designed to function dynamically with sediment deposition as their size and shape adapts to increased deposition
Biological processes			
Maintain characteristic plant community	Species composition and physical characteristics of living plant biomass	Species composition and structure, regeneration, canopy cover, density of all vegetation, and basal area of trees have a direct effect on wildlife habitat, sediment deposition, floodwater storage, transpiration, nutrient cycling, and other functions	The planned wetland plant community must be able to function with the planned hydroperiod, water depths, management, structure operation, and habitat needs. Vegetation slows water velocity, takes up nutrients, provides cover, and a host of other factors. Methods of establishment, cost, required maintenance, and invasive species competition must be taken into account
Maintain spatial structure of habitat	The capacity of a wetland to support animal populations and guilds by providing heterogeneous habitats	The microtopography and macrotopography required to provide hydrologic diversity go hand in hand with creating a heterogeneous plant community which provide diverse habitats	The plan should provide for diversity of age and strata, horizontal and vertical structure, patchiness, and canopy gaps, which are matched with varying water durations and depths to provide a self-sustaining system. Microtopography usually provides an increase in this function

Table 13–1 Common wetland functions and processes—Continued

Function	Description	Function interaction	Planning/design considerations
Biological processes—Continued			
Maintain interspersion and connectivity	The capacity of a wetland to permit aquatic organisms to enter and leave the wetland via permanent or ephemeral surface channels, overbank flow, or unconfined hyporheic aquifers. The capacity of a wetland to permit access of terrestrial or aerial organisms to contiguous areas of food and cover	Increase in function of dynamic and long-term surface water storage provides increased connectivity to adjacent wetlands and streams for aquatic organisms. Increase of microtopographic complexity provides diverse hydrologic and vegetative conditions. Increase of spatial structure of habitat also provides increased connectivity	The physical substrate (land surface) of a wetland can provide the requisite conditions for a vegetative community, which provides connectivity. The planning and design of structures should consider provision for passage of aquatic and terrestrial organisms. Specific fish and herpetofauna structures can be considered
Maintain distribution and abundance of Invertebrates	The capacity of a wetland to maintain characteristic density and spatial distribution of invertebrates (aquatic, semiaquatic, and terrestrial)	Hydrologic, vegetative, and soil condition factors combine to provide conditions which improve the abundance of invertebrates	Wetland soil, decomposing leaf litter and coarse woody debris, and diverse aquatic water depths all contribute to an increase in this function. Microtopography usually provides an increase in this function
Maintain distribution and abundance of vertebrates	The capacity of a wetland to maintain characteristic density and distribution of vertebrates (aquatic, semiaquatic, and terrestrial)	Fish, birds, herpetofauna, and mammals use wetlands for part or all of their life cycle. The wetland vegetation, hydrology, and physical substrate relate directly to the quality of this function	Each wetland type and location must be carefully evaluated for the needs of local vertebrates. Fish and other aquatic organism passage may be a critical need. Waterfowl nesting and rearing are common concerns. Aquatic mammals such as river otters may need consideration. The design must consider the needs and challenges of mammals such as beaver, muskrat, and nutria
Rare and declining habitat	Vernal pools, high plains playas, wet savannas, prairie potholes, pocosins, and other habitats are either a rare habitat type or have been degraded more than other types	Diversity in habitat types across landscapes creates more opportunities for plants and wildlife. The rarity of certain habitats decreases these opportunities. Habitat loss is responsible for 85% of the imperiled plant and animals in the U.S. Restoration of rare and declining habitats could significantly alleviate further degradation of these species	The importance of specific wetland types will vary by region and state. Design wetlands to mimic the hydrology and ground surface microtopography of undisturbed habitats of the kind being restored. Replication of vegetation by specific species will be critical to this function

Sources of information that should be reviewed include the USFWS National Wetland Inventory maps, state wetland inventory maps (NRCS), U.S. Geological Survey (USGS) Topographic Quadrangle maps, geographical information system (GIS) data from Federal and state agencies, and wetland status and trend information from various agencies and groups (USFWS (*http://www.fws.gov/nwi*)). Historical aerial photography, such as Farm Service Agency (FSA) 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. Flood plain elevations can often be determined from sources such as the Federal Emergency Management Agency (FEMA). Land user 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, preexisting 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, enhancement, or creation. 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 in planning. More information regarding this ecological planning approach can be obtained from the journal *Landscape Ecology*, published by Springer Science+Business Media B.V., as well as other journals and publications. A key factor in the landscape scale 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 preexisting hydrologic soil conditions, better biological conditions such as seed-containing soils, and faunal recovery possibilities from adjacent areas. Wetland enhancement may be considered to improve wetland functions and values for a specific suite of species. 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. For sites where conditions for wetland creation are suitable, features such as aspect, depth, dominant vegetation, sediment and detrital loading, light and wind exposure should be considered, as they are important in shaping an individual wetland's thermal, nutrient, hydrologic, and chemical dynamics, which strongly influence a wetland's resultant floral and faunal assemblages.

When investigating wetland functions, the planner should consider regional, watershed, and decision-maker objectives in setting priorities for restoration, enhancement, or creation. Table 13–1 lists 11 commonly considered functions, three wetland processes, and provides descriptions, some interactions between functions, and planning/design considerations for each. This list is not all-inclusive. Examples of multifunctional wetlands are shown in figure 13–7.

(c) Planning step 3—Resource inventory Planning step 4—Data analysis

Data collection and analysis is the first phase of site evaluation in planning a wetland project. The data collection and analysis done in these steps need not be to the level necessary for engineering design. However, design data may be collected and analyzed during the planning phase for future use. 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.

As a general guideline, the following items should always be obtained during planning:

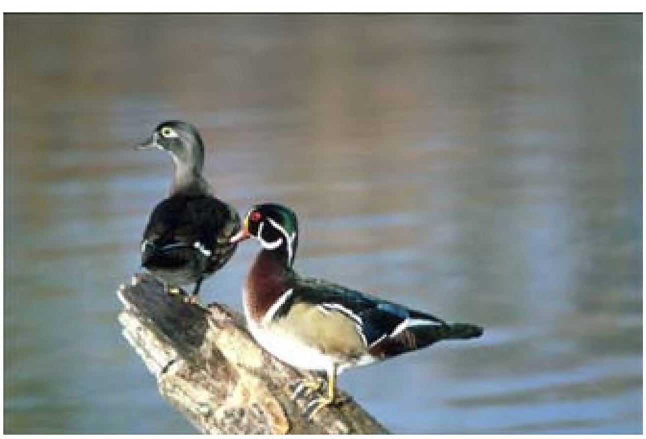
- soils map, with physical and engineering interpretations—Web Soil Survey or published soil survey. It may be appropriate to perform onsite investigations during this phase to determine soil texture, measure hydraulic conductivities, conduct geologic investigations, test for nutrients, pH, salinity, and contaminants, determine water holding capacity, and perform engineering analysis.
- hydrologic data—as appropriate, obtain enough information to determine the feasibility of project alternatives. This may include drainage area,

Figure 13–7 Wetland functions and values

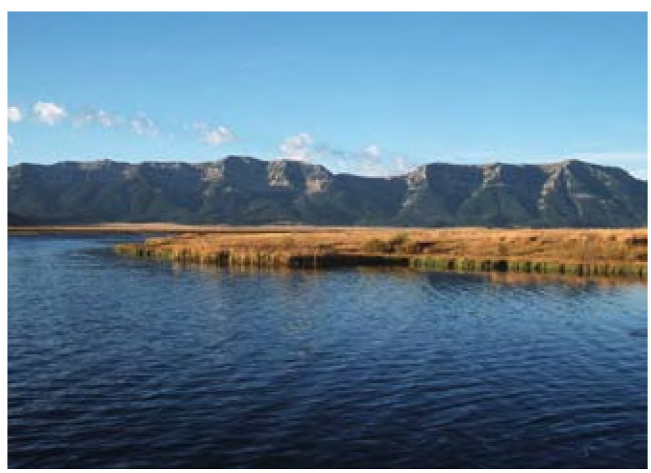
(a) Dynamic surface water storage

(b) Removal of imported elements and compounds

(c) Maintain distribution and abundance of vertebrates



(d) Values—aesthetic quality and open space



(including hydrologic soil group and land use and cover information), climate data (including WETS table), and stream records. In some cases, this is the step where complex hydrologic analysis is required. This may include runoff hydrographs, stream hydrographs and duration curves, evapotranspiration studies, and ground water investigations. An evaluation of the drainage area should be made that includes current soil erosion rates, sources of point and nonpoint pollution, and potential changes of land use which would affect the function of the project.

- project boundaries—in most cases, the selection of project boundaries can be based on the boundary of the landscape position which supports the HGM wetland class present; for example, a riverine wetland should ideally contain the active flood plain along a stream reach along one or both sides of the channel.
- wetland determination for current and former wetlands—this should be done according to the three-factor approach of wetland hydrology, hydric soil, and hydrophytic vegetation used in the Wetlands Research Program Technical Report Y–87–1, Corps of Engineers Wetland Delineation Manual (COE 87M) and regional supplements; however, the level of detail used for delineations is usually not necessary.
- existing drainage systems, including tile lines, drainage ditches, road ditches, culverts, and any other surface and subsurface features, affecting the direction of movement and quantity of water delivered to the project site
- aerial photographs, USGS topographic maps, or GIS layers that include orthophotography, digital elevation model, and soils information
- Federal, state, and local regulations that apply to the site
- information required in the area to perform NEPA evaluation, including threatened and endangered species, and cultural resources
- location of all utilities, roads, and other easements

Other data needed depending on wetland HGM type and planned functions may include:

- survey landscape context to determine landscape corridors that link habitat areas such as stream zones, ephemeral wet areas, woodlots, and others
- detailed topographic surveys and/or cross section and profile surveys
- vegetative surveys, including elevations and species noted in the area
- fish and wildlife habitat evaluations, including the habitat needs for nesting, rearing, breeding, spawning, and other activities throughout their life cycle; this should include the connectivity requirements between the wetland and streams, uplands, or other landscape positions; this has a direct effect on the planned wetland components, hydroperiod, and hydrologic regime
- landscape use and aesthetic quality evaluations
- water quality data

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 on wetland creation projects than on restorations or enhancements.

Large projects may have the potential to involve multiple landowners or units of government. Small projects may have the potential to become incorporated with existing or planned adjacent wetland projects. The resource inventory phase should include information necessary to make planning alternatives that utilize this potential. This may be as simple as discussing these possibilities with landowners and documenting the results. Or, it may involve researching the needed easements, permits, or studies required to satisfy the requirements of a drainage district, levee district, or state and Federal agencies.

Following is additional discussion of some of the items to be considered.

(1) Soils

Soils at the site of the proposed wetland must be assessed for overall suitability. Water holding capabilities are influenced by soil texture, organic matter content, and drainable porosity. Clays and loams generally retain moisture through capillary forces higher in the soil profile than sands and sandy loams. The coarse textured soils may result in having "drier" plant communities, depending on water level. The soil's suitability to support the planned plant community should be evaluated. The Web Soil Survey or published soil survey may provide physical and chemical interpretations for wetland vegetation.

The suitability of soils for construction should be evaluated during a geologic investigation. This includes logging in accordance with the Unified Soil Classification System (USCS) and may include collection of undisturbed samples for analysis of strength, consolidation, settlement, erodibility, and permeability. If there is the potential for soil dispersion, this analysis should be included, as well. Potential borrow sites (on or offsite), as well as structure foundations should be investigated.

During the site evaluation of the soils, any suspected topsoil 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

(i) Quality—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 may need inventory and evaluation.

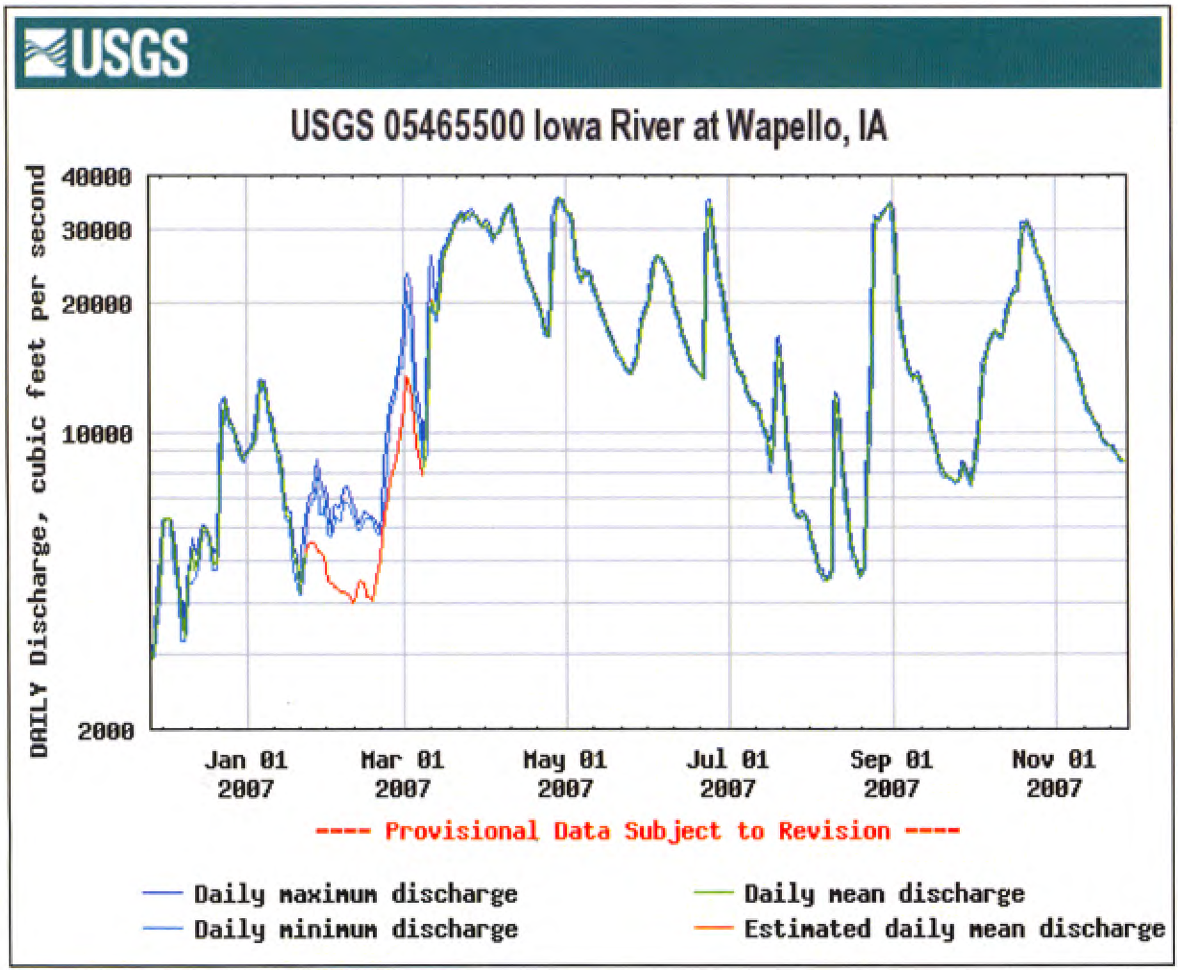
(ii) Quantity—In evaluating the suitability of a site, the source of the water that will supply the wetland must be carefully considered. Wetlands exist where inundation or saturation occurs for long enough periods to support anaerobic soil conditions and support hydrophytic vegetation. In addition, these conditions must provide the hydroperiod and hydrologic regime needed to meet the planned wetland function. In some instances, a site may be selected that will require pumping or diverting of water from an offsite 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 offsite sources may require permits in several states and may be affected by water rights laws.

(iii) Storm event discharge—The resource inventory should include data in sufficient detail to determine the need for structure reservoir routing, whether the site is subject to active flood plain inundation or if it is supplied with perennial baseflow from offsite. This data is critical in selecting and locating wetland components. Figure 13–8 shows an example of stream gage data.

(3) Vegetation

When plans are relatively firm for the type or HGM class of wetland to be restored, enhanced, or created, the plans for site revegetation must be determined. It is critical that the project objectives, wetland HGM class, depths and durations, and desired species composition be determined up front. Once this has been done, decisions can be made as to whether the site needs to be revegetated as a whole, partially revegetated, enhanced with specific plantings, or whether the site can naturally revegetate on its own from a viable seed bank, seed wall, or by overbank flooding. Should the site be left to revegetate naturally, an evaluation of the desired species must be considered in relation to the existing propagules sources, as well as the likelihood of invasion by noxious, invasive, or problem species. Other criteria such as site conditions, budget, and seed availability are to be included into the decision; however, the site should be revegetated with the selected desirable species as quickly as possible. Otherwise, the site may revegetate with an inappropriate group of species and/or invasive species. Appendix C, parts 7 through 10, contains a checklist which provides some general guidelines in assessing vegetation and revegetation approaches based on planning considerations, vegetative community conditions, and function objectives. The determination of plant species value for wildlife and for erosion control can be found in the FOTG and other field office reference ma-

Figure 13–8 Riverine wetland planning may involve streamflow data collection



terials. The vegetation plan should include an assessment of land cover patterns on the landscape and indicate how the wetland fits into a larger pattern of habitats for wildlife.

(4) Wildlife and fish

Wildlife and fish use will change post-restoration, and it is important to quantify and document these use changes. This documentation is important not only to stay in compliance with NEPA requirements but also for accountability (what are we getting for our money). There are several recognized methods for site evaluation for wetland wildlife and fish. For small sites, simple surveys such as transects or call surveys conducted throughout a season, may suffice. For larger sites, more detailed evaluations that can help to accurately quantify wildlife and fish use can be used. Many of these incorporate models to assess the documented change. Some of these methods include (but are not limited to) the Habitat Evaluation Procedure (HEP), Wetland Evaluation Technique (WET), Index of Biotic Integrity (IBI), and individual state assessment methods. Each evaluation method has its strengths and limitations, so it is important that the user choose a method that will meet his or her needs. A good overview of wildlife evaluation methods as they pertain to wetlands can be found in A Comprehensive Review of Wetland Assessment Procedures: A Guide for Wetland Practitioners (Bartoldus 1999). State fish and wildlife agency biologists, Federal and local government biologists, nongovernmental organization biologists, academic and professional biologists, and published guidelines are an excellent source of species-specific habitat information.

(5) Plants and animals that may pose wetland management challenges

Restoring, enhancing, or creating wetlands may attract new or increased numbers of plant and animal species, some of which may prove to be a management challenge. In natural wetland communities, keystone species such as the beaver, muskrat, crayfish, and alligator establish and maintain heterogeneity within wetland systems through the process of their activities. These same activities may pose unique challenges to the design and maintenance of wetlands restored to meet specific functions utilizing traditional restoration methods. Embracing such organisms and their activities through innovative design and management will reduce long-term maintenance costs while promoting natural processes that will allow for natural variability and sustainability in wetland communities and functions. Listed below are some of the more common problem species and planning considerations for their control.

(i) Waterfowl—In urban and industrial areas, large numbers of ducks and geese have the ability to damage lawns and landscaped areas (fig. 13–9). Overuse by waterfowl can damage community parks or make them unpleasant to humans, and large numbers of waterfowl can adversely affect water quality in water supply reservoirs. Due to excessive waterfowl waste, wetlands may receive a high load of organics and become a source of unpleasant odors and mosquitoes. Discouraging the public from feeding waterfowl and planting a vegetated border of tall, rigid stemmed herbaceous vegetation around the wetland are ways to deter waterfowl loafing. It would not be prudent to locate wetlands that attract large numbers of geese near urban airports.

(ii) Mosquitoes—Dozens of mosquito species may breed in a wetland, but very few of these species, termed vector mosquitoes, are of concern to humans. Vector mosquito species generally breed in shallow, stagnant water where they are safe from predators and in waters that have high organic content in degraded wetlands with a compromised ecological community. To reduce the attractiveness of a wetland to breed-

Figure 13–9 Wetlands near airports can pose waterfowl management problems

ing mosquitoes, addressing nutrient and organic enrichment concerns and stabilizing hydrology within the wetland is of utmost importance, especially in urban areas. In addition, some species of mosquito avoid breeding in waters that house a diverse community of predatory insects or a large number of organisms that would compete for the same food resources as mosquito larvae. Thus, managing for a diverse ecological community can help to deter and control mosquito reproduction in wetlands.

In wetlands designed to maintain fish or that naturally house wetland fish species, vector mosquitoes may not be a problem unless there are extensive areas of shallow water less than 6 inches deep with fine-stemmed vegetation where fish can not maneuver. In some situations, it may be acceptable for populations of small, native wetland fish to be stocked and managed in suitable habitat within their natural range to provide mosquito larvae control. Before introducing any species of fish, local fisheries experts should be consulted, and careful consideration should be given to possible adverse impacts on populations of other native species, fish or otherwise.

The use of pesticides within wetlands to control mosquitoes is generally not recommended unless used as a last resort in areas where human health concerns are high. An exception to this would be applying pesticides to treatment wetlands that receive high levels of pollutants and do not support diverse biotic assemblages of plants and animals. Pesticides must be chosen carefully and applied following label instructions. The application of pesticides to wetlands could have significant negative impacts on nontarget species.

Bacillus thuringiensis israelensis or *Bacillus sphaericus* (BTI) is a biocontrol microbial larvicide which is ingested by and kills mosquito and other true fly (Dipteran) larvae. To date, BTI is not known to harm other insect or vertebrate species. True fly larvae are critically important decomposers of organic material and are the most abundant macroinvertebrate prey within wetland sediments. Keeping this in mind, treating wetlands with BTI to reduce mosquito concerns could have the potential to negatively impact other true fly species and their predators, a consideration that must be addressed especially when providing adequate wildlife habitat and food resources are targeted goals for wetland management.

Artificial wetland drawdown or drainage is a common, but ineffective practice used to control mosquitoes in some areas. The act of draining wetlands increases the amount of shallow, stagnant, short hydroperiod pools preferred by mosquitoes, while reducing the populations of organisms that prey on and compete with mosquito larvae. Contrary to traditional wetland drainage measures, restoring and maintaining a wetland's hydrology within the realm of historic, natural variability will have a greater effect in controlling mosquito populations without compromising nontarget organisms or other wetland functions. Reducing wetland access, using repellents, wearing appropriate clothing, and avoiding wetlands during peak mosquito activity periods and seasons are effective means in avoiding mosquito nuisance concerns.

(iii) Fish—Carp and other rough fish that invade wetlands can potentially destroy the aquatic plant community or compete with wetland animals for resources, reducing populations of desirable plants and animals. Designing wetlands that will experience natural drawdown due to seasonal or semipermanent hydrology will allow for natural control against rough fish. Although fish populations can be reduced by netting, the most effective method of rough fish control in permanent wetlands equipped with water control structures is to conduct a complete drawdown 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. Careful timing of water drawdown and potential impacts to nontarget plants and animals should be considered.

Wetlands with inflows or outflows connected to other water bodies may allow for fish passage and may require barriers to fish movement to keep undesirable fish out of, or in some circumstances within, the wetland being managed.

(iv) Vegetation—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), nutrient-enriched wetland, eliminating other desirable vegetation or open water habitat. However, dense stands of cattails can also provide water quality benefits by removing nutrients and pollutants and 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. Vegetation can be controlled chemically, mechanically, biologically, or a combination thereof. For sites with foreseen vegetation management challenges, water control structures may be planned to facilitate complete drainage and tillage of the wetland bottom or that allow water depth to be increased by at least 3 feet for a growing season. In addition, muskrats can be used as biological control agents for cattails, as can beavers for tree control.

(v) Mammals **—**It is claimed that the beaver is a close second to humans in the ability to change a landscape. For this reason, beavers can commonly become a problem within wetlands and along streams where they may burrow into banks or dikes or dam outflows (fig. 13–10). Adjacent to urban areas and within tree plantings, beavers may 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.

Muskrat and nutria are two other mammals that can cause problems in permanent water over 3 feet deep (fig. 13–11). 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. This same technique works well in circumstances where burrowing crayfish may be of concern to the stability of structures. If muskrats or nutria 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. For example, animals will colonize new areas if they can move upstream and

Figure 13–10 Beavers can be a nuisance animal

Figure 13–11 Muskrats can damage earthen dikes

downstream under cover with relative safety. Such cover can be rapidly developed through the use of soil bioengineering revegetation techniques or riparian plantings, 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. Fish and other aquatic species will inhabit wetlands that are hydrologically connected to streamflow during seasonal high flows. Where practical, restore wetland complexes that maximize biological diversity. Temporally and spatially, flood plain wetlands are key components of a river and its flood plain. Dry secondary channels and backwaters of rivers are re-wetted as the river rises during seasonal rains and isolated wetlands are reconnected to the river when discharge exceeds bankfull. The presence of such a dynamic connection between the stream and the riparian corridor maximizes the diversity of hydroperiod and hydrologic regime and increases the value of the associated function variables.

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.

Placing wetlands in headwaters of coldwater fish streams may adversely affect trout, salmon, and other coldwater fish since it can raise stream temperatures or decrease dissolved oxygen (fig. 13–12).

(7) Recreation

Wetlands can accommodate direct human use and recreation consumptive uses, such as hunting and fishing, and nonconsumptive uses such as educational tours and lectures, bird watching, nature trails, boating, hiking, jogging, biking, and horseback riding (fig. 13–13). 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

Figure 13–12 Salmonids may be adversely affected by water warmed by wetlands

Figure 13–13 Wetlands provide nonconsumptive recreational use

part of the wetland. 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.

Structures should neither detract from the wetland nor interfere with its biologi cal or other functions. For example, avoid placing trails or access roads through large homogenous ecosystems of core habitat to preserve as much interior biotic environment as possible. Trails should be located along the outer edge of a buffer zone which protects core habitat from disturbance. The attributes of a buffer zone should be defined early in the planning stages, with acceptable uses within the buffer zone clearly defined. It is also pertinent that linear barriers to animal movement, such as roads or wide trails, not be placed between important patches of habitat, for example, a road that parallels a water body, thereby cutting off bottomland to upland passage. In situations where such a barrier is unavoidable, planning for safe passageways (constructing crossings and/or barriers, or using traverse-friendly materials) may improve the ability for animal movement over, above, below, or along an obstacle.

Technical guides for designing recreational structures and facilities are available from the USACE, the USFWS, 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.

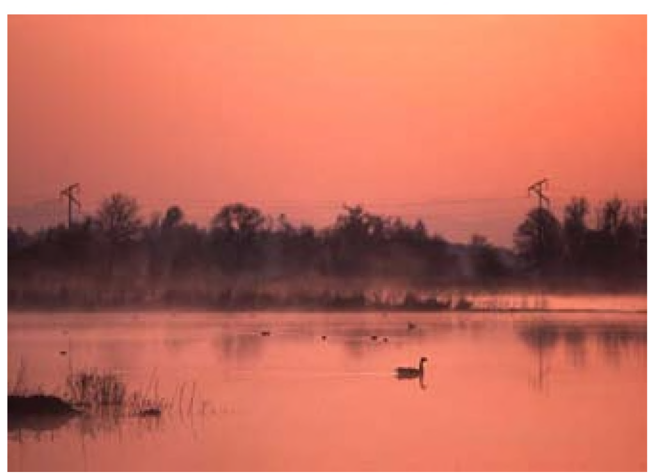
Landowners may be reluctant to adopt conservation practices or landscape features that contradict aesthetic norms for attractive or well-cared-for land. A landowner's willingness to cooperate in wetland restoration or enhancement activities or to manage and protect a wetland over the long term can be 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 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. 13–14). 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

Specific wetland benefits have always been valued, to a certain extent, throughout history. Wetland's clean, fresh water and abundant game made them attractive camp and settlement sites. Because of this, cultural resources may be encountered in and around wetland landscapes. These may include archeological sites, earthen features, and historic structures and buildings. Also, wetlands have unique preservation potential because they have low oxygen and high acidity, which reduce decay or bacterial breakdown. This means that preserved artifacts are more likely under these conditions.

Figure 13–14 Wetlands provide open space in manmade landscapes



Cultural resources need to be considered early in the planning process. Both NRCS General Manual (Title 420, Part 401.20) and the National Cultural Resources Training Program provide guidance for this process. They also contain procedures for when cultural resources are unexpectedly discovered. Planners need to work closely with landowners, an NRCS cultural resources coordinator, the State Historic Preservation Office, or Native American groups to ensure that proposed practices or installation do not harm significant cul tural resources. This process is required by several Federal and state cultural resource laws and may be a requirement for a Clean Water Act, Section 404 permit.

(10) Social

Planners should work closely with the landowner during the planning process to ensure that their objectives are incorporated into the design when feasible. Due to Federal, state, and local regulations, the potential for con flict may exist between the landowner, planners, and other agencies. It is important for planners to recognize this potential and keep the landowner informed during the planning process. It is also important to be aware of any perceived or real impacts outside of the project area and its implications. For example, a restoration may not be hydrologically affecting adjacent landowners, but the perception may be different, so local informational public meetings may be needed to inform and educate those involved.

The NRCS Social Science Team (*www.ssi.nrcs.usda.gov*) has developed a broad array of guidelines and publications regarding the social components of conservation that can be very helpful when planning any conservation related project. These are available on the NRCS Web site under Technical Resources and Social Sciences.

(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, flood-flow 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 nonmonetary 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 decision maker, both the monetary and nonmonetary 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 NRCS, USFWS, NOAA National Marine Fisheries 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 regulation

It may be necessary to obtain Federal, state, or local permits prior to wetland restoration, enhancement, or creation. It is important to be aware of these regulatory issues during planning before designs are completed. Restrictions may exist that prevent the project from being designed as originally conceived.

(i) Section 404–Clean Water Act—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. Per mits are evaluated and issued by the USACE 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 wet land construction project. In general, wetland restorations are covered under the Nationwide Permit No. 27 for Section 404 purposes. Contact with the local USACE permitting office is always a good idea to verify the project falls under the scope of the Nationwide Permit.

(ii) Water storage and diversion —Water law and water rights vary from east to west and state to state and can be very complicated. Western 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 abso lutely 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.

Eastern water rights or riparian rights rely on ownership of land along a water way and can include public navigability rights. In some states, a restoration on private land connected to public waters may make private waters public, so specific restoration designs may be necessary to protect a landowner's rights and interests.

(iii) Flood plain—In flood plains included in the National Flood Insurance Program, is necessary to obtain a local permit for a project which has the potential to raise the 100-year flood elevation. Normally, it is prohibited to raise the flood elevation in the defined floodway, and areas outside the floodway are limited to 1 foot or less increase in flood elevation. It may be necessary to perform complex water surface profile analysis to document the projects effects on the flood elevation for a permit. The local permit program is usually administered by city or county government. The permitting entity will have information about the FEMA funded flood studies, and data needed to perform an analysis. Most NRCS field offices have copies of the FEMA flood study maps for their district.

Projects which store water above natural ground and/or include dikes can potentially increase the flood elevation.

(iv) Dam safety—The requirements for dam safety permits vary widely across the country. The need for permits is usually based on some combination of storage volume and structure height. Many states consider embankments of 6 feet or less in height to be dams, and many wetland embankments store significantly more water above natural ground than the typical embankment pond.

(v) National Point Discharge Elimination System —The EPA's National Pollutant Discharge Elimination System (NPDES) permit system is usually administered by the states. It requires permits for construction activities which have the potential to discharge sediment and other pollutants from construction sites until permanent cover has been established. Best Management Practices for sediment control, discharge of hazardous construction materials, and control of spills of equipment fuels and lubricants are usually required. Individual states have set permit requirements based on location of the activity, and size of the disturbed area. The permits are administered by the state agency responsible for environmental protection.

(vi) Easements—The number of potential easements on a project site are too numerous to mention in their entirety. Easements are recorded on property ownership documents. They may require a project proponent to obtain permission from the easement holder to conduct the activity. The following are some of the most common easement issues:

(vii) Utilities—Buried or overhead electrical, telephone, oil, gas, water, and other utilities owners will always have an easement across the property and will almost certainly have a concern with the alteration of the land over or under their easement or the construction activity.

They commonly require, at a minimum, that constructed access routes be maintained through the project. It is common to require the owner to pay the expense of new construction and land rights to relocate the utility.

(viii) Water storage or flowage—The landowner of a wetland project must obtain an easement for any water stored on an adjoining property, both permanently or temporarily. Also included are any waters diverted away from their original, natural flow path. Many states have defined the minimum return period of the storage event. It is easy to overlook water storage requirements under state laws.

An example would be a wetland structure designed to safely handle a 10-year storm discharge. The top of this structure was lower than the lowest elevation along the upstream property line. However, state law required that an easement be obtained up to the water surface during a 100-year runoff event. This same structure, when overtopping during the 100-year event, would back water across the property line.

(ix) Irrigation, drainage, and levee districts—These entities often have easements on ditches, canals, dikes, levees, or other features in a wetland project area. In some cases, the actual boundary and width of these easements are indeterminate. Also, many old easement holding entities have disbanded, merged with other entities, or turned their easement over to another entity. In addition to easements, there may be set-back requirements. For instance, the USACE usually has a set-back distance for excavations adjacent to its project levees.

(d) Planning step 5—Formulate alternatives

Once the problem is defined, objectives are set, and data is collected and analyzed, project alternatives can be developed. It is recommended that at least two alternatives, which are in keeping with the project objectives, be developed.

(e) Planning step 6—Evaluate alternatives

Alternatives are analyzed by the project's decision makers and based on many factors. The following is a list of factors which should be considered:

- *Construction cost*—reflects the availability of materials, equipment, and construction contractors locally available to do the work. It also reflects the relative difficulty of constructing the wetland components.
- *Maintenance costs*—estimated costs for keeping constructed structures, vegetation, etc., in the condition required for the planned wetland function throughout the life of the project components.
- *Management costs*—includes the costs, required skill and experience, and time required to manage the planned wetland components in accordance with project objectives. Although some of these factors are subjective and qualitative, an effort should be made to assign costs. Included are costs for invasive species control, mowing, water control structure operation, etc.
- *Projected life span of components*—takes into account the cost of replacement, rehabilitation, and maintenance of wetland components. These efforts can be used to determine a life cycle cost for the project alternative.
- *Project benefits*—can be addressed by using the local HGM class functional assessment to determine which alternative has the highest increase in function. Although it is difficult to assign a monetary value to functions, it is still useful for comparisons with other costs.

Other factors to consider include:

- relative aesthetic quality
- other landowner or societal benefits beyond the project objectives
- flexibility of the project in terms of future modifications or merging with future adjacent projects