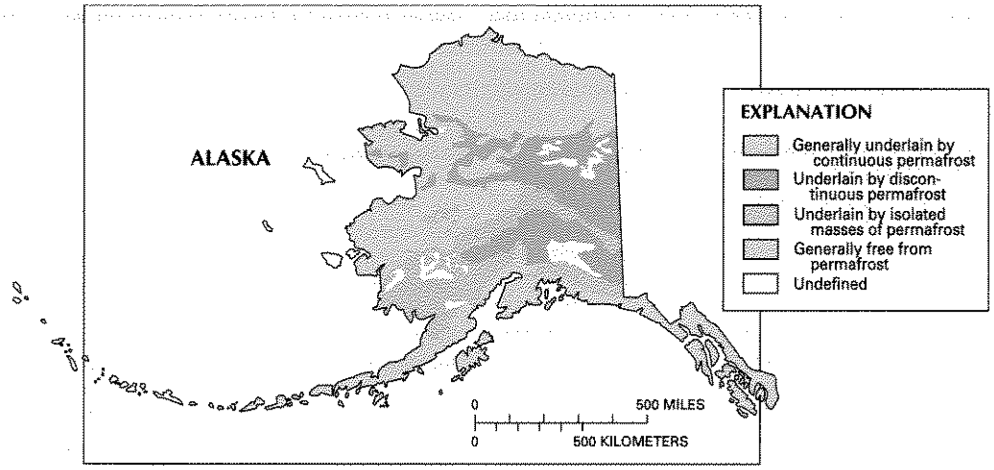

Figure 25. Continuous, discontinuous, and sporadic permafrost areas of Alaska. *(Source: Modified from Ford and Bedford, 1987.)*

dominated by surface-water inflow and outflow reflect the chemistry of the associated rivers or lakes. Those wetlands that receive surface-water or ground-water inflow, have limited outflow, and lose water primarily to ET have a high concentration of chemicals and contain brackish or saline (salty) water. Examples of such wetlands are the saline playas, wetlands associated with the Great Salt Lake in Utah, and the permanent and semipermanent prairie potholes. In contrast, wetlands that receive water primarily from precipitation and lose water by way of surface-water outflows and (or) seepage to ground water tend to have lower concentrations of chemicals. Wetlands influenced strongly by ground-water discharge have water chemistries similar to ground water. In most cases, wetlands receive water from more than one source, so the resultant water chemistry is a composite chemistry of the various sources.

Plants can serve as indicators of wetland chemistry. In tidal wetlands, the distribution of salty water influences plant communities and species diversity. In freshwater wetlands, pH (a measure of acidity or alkalinity) and mineral and nutrient content influence plant abundance and species diversity.

HYDROLOGIC AND WATER-QUALITY FUNCTIONS OF WETLANDS

Wetland hydrologic and water-quality functions are the roles that wetlands play in modifying or controlling the quantity or quality of water moving through a wetland. An understanding of wetland functions and the underlying chemical, physical, and biological processes supporting these functions facilitates the management and protection of wetlands and their associated basins.

The hydrologic and water-quality functions of wetlands are controlled by the following:

- Landscape position (elevation in the drainage basin relative to other wetlands, lakes, and streams)
- Topographic location (depressions, flood plains, slopes)
- Presence or absence of vegetation
- Type of vegetation
- Type of soil
- The relative amounts of water flowing in and water flowing out of the wetland
- Local climate
- The hydrogeologic framework
- The geochemistry of surface and ground water

Although broad generalizations regarding wetland functions can be made, effectiveness and magnitude of functions differ from wetland to wetland.

Natural functions of wetlands can be altered or impaired by human activity. Although slow incremental changes in the natural landscape can lead to small changes in wetlands, the accumulation of these small changes can permanently alter the wetland function (Brinson, 1988). Some of the major hydrologic and water-quality functions of wetlands—(1) flood storage and stormflow modification, (2) ground-water recharge and discharge, (3) alterations of precipitation and evaporation, (4) maintenance of water quality, (5) maintenance of estuarine water balance, and (6) erosion reduction—are discussed below.

The effectiveness and magnitude of a function varies from wetland to wetland.

Flood Storage and Stormflow Modification

Wetlands associated with lakes and streams store floodwaters by spreading water out over a large flat area. This temporary storage of water decreases runoff velocity, reduces flood peaks, and distributes stormflows over longer time periods, causing tributary and main channels to peak at different times. Wetlands with available storage capacity or those located in depressions with narrow outlets may store and release water over an extended period of time. In drainage basins with flat terrain that contains many depressions (for example, the prairie potholes and playa lake regions), lakes and wetlands store large volumes of snowmelt and (or) runoff. These wetlands have no natural outlets, and therefore this water is retained and does not contribute to local or regional flooding.

A strong correlation exists between the size of flood peaks and basin storage (percentage of basin area occupied by lakes and wetlands) in many drainage basins throughout the United States (Tice, 1968;

Hains, 1973; Novitzki, 1979, 1989; Leibowitz and others, 1992). Novitzki (1979, 1989) found that basins with 30 percent or more areal coverage by lakes and wetlands have flood peaks that are 60 to 80 percent lower than the peaks in basins with no lake or wetland area. Wetlands can provide cost-effective flood control, and in some instances their protection has been recognized as less costly than flood-control measures such as reservoirs or dikes (Carter and others, 1979). Loss of wetlands can result in severe and costly flood damage in low-lying areas of a basin.

Not all wetlands are able to store floodwaters or modify stormflow; some, in fact, add to runoff. Downstream wetlands, such as those along the middle and lower reaches of the Mississippi River and its tributaries, are more effective at reducing downstream flooding than are headwater wetlands, largely as a result of larger storage capacities (Ogawa and Male, 1986). Runoff from wetlands is strongly influenced by season, available storage capacity, and soil permeability. Wetlands in basin headwaters are commonly sources of runoff because they are ground-water discharge areas. Wetlands in Alaska that are underlain by permafrost have little or no available storage capacity; runoff is rapid and flood peaks are often very high.

Wetlands can influence weather and climate.

Ground-Water Recharge and Discharge

Ground-water recharge and discharge are hydrologic processes that occur throughout the landscape and are not unique functions of wetlands. Recharge and discharge in wetlands are strongly influenced by local hydrogeology, topographic position, ET, wetland soils, season, and climate. Ground-water discharge provides water necessary to the survival of the wetland and also can provide water that leaves the wetland as streamflow. Most wetlands are primarily discharge areas; in these wetlands, however, small amounts of recharge can occur seasonally.

Recharge to aquifers can be especially important in areas where ground water is withdrawn for agricultural, industrial, and municipal purposes. Wetlands can provide either substantial or limited recharge to aquifers. Much of the recharge to the Ogallala aquifer in West Texas and New Mexico is from the 20,000 to 30,000 playa lakes rather than from areas between lakes, ephemeral streams, and areas of sand dunes (Wood and Osterkamp, 1984; Wood and Sanford, 1994). Recharge takes place through the bottoms of some streams, especially in karst topography and in the arid West. Some recharge also takes place when floodwater moves across the flood plain and seeps down into the water-table aquifer. Cypress domes in Florida and prairie potholes in the Dakotas also are thought to contribute to ground-water recharge (Carter and others, 1979). Ground-water recharge from a wetland can be induced when aquifer water levels have been drawn down by nearby pumping.

Most estuarine wetlands are discharge areas rather than recharge areas, primarily because they are on the low topographic end of local and regional ground-water flow systems. As the tide rises, water is temporarily stored on the surface of the wetland and in the wetland soils, where it mixes with the discharging freshwater. The water moves back into the estuary or tidal river as the tide ebbs. Precipitation falling on nontidal freshwater wetlands on barrier islands may recharge the shallow freshwater aquifer overlying the deeper salty water.

Alterations of Precipitation and Evaporation

Wetlands can influence local or regional weather and climate in several ways. Wetlands tend to moderate seasonal temperature fluctuations. During the summer, wetlands maintain lower temperatures because ET from the wetland converts latent heat and releases water vapor to the atmosphere. In the winter, the warmer water of the wetland prevents rapid cooling at night; warm breezes from the wetland surface may prevent freezing in nearby uplands. Wetlands also modify local atmospheric circulation and thus affect moisture convection, cloud formation, thunderstorms, and precipitation patterns. Therefore, when wetlands are drained or replaced by impermeable materials, significant changes in weather systems can occur.

Maintenance of Water Quality

Ground water and surface water transport sediments, nutrients, trace metals, and organic materials. Wetlands can trap, precipitate, transform, recycle, and export many of these waterborne constituents, and water leaving the wetland can differ markedly from that entering (Mitsch and Gosselink, 1993; Elder, 1987). Wetlands can maintain good quality water and improve degraded water.

Water-quality modification can affect an entire drainage basin or it may affect only an individual wetland. Water chemistry in basins that contain a large proportion of wetlands is usually different from that in basins with fewer wetlands. Basins with more wetlands tend to have water with lower specific conductance and lower concentrations of chloride, lead, inorganic nitrogen, suspended solids, and total and dissolved phosphorus than basins with fewer wetlands. Generally, wetlands are more effective at removing suspended solids, total phosphorus, and ammonia during high-flow periods and more effective at removing nitrates at low-flow periods (Johnston and others, 1990). Novitzki (1979) reported that streams in a Wisconsin basin, which contained 40 percent wetland and lake area, had sediment loads that were 90 percent lower than in a comparable basin with no wetlands. Wetlands may change water chemistry sequentially; that is, upstream wetlands may serve as the source of materials that are transformed in downstream wetlands. Estuaries and tidal rivers depend on the flow of freshwater, sediments, nutrients, and other constituents from upstream.

Wetlands filter out or transform natural and anthropogenic constituents through a variety of biological and chemical processes. Wetlands act as sinks (where material is trapped and held) for some materials and sources (from which material is removed) of others. For example, wetlands are a major sink for heavy metals and for sulfur, which combines with metals to form relatively insoluble compounds. Some wetland mineral deposits (bog iron, manganese) are or have been important metal reserves in the past. Organic carbon in the form of plant tissues and peat

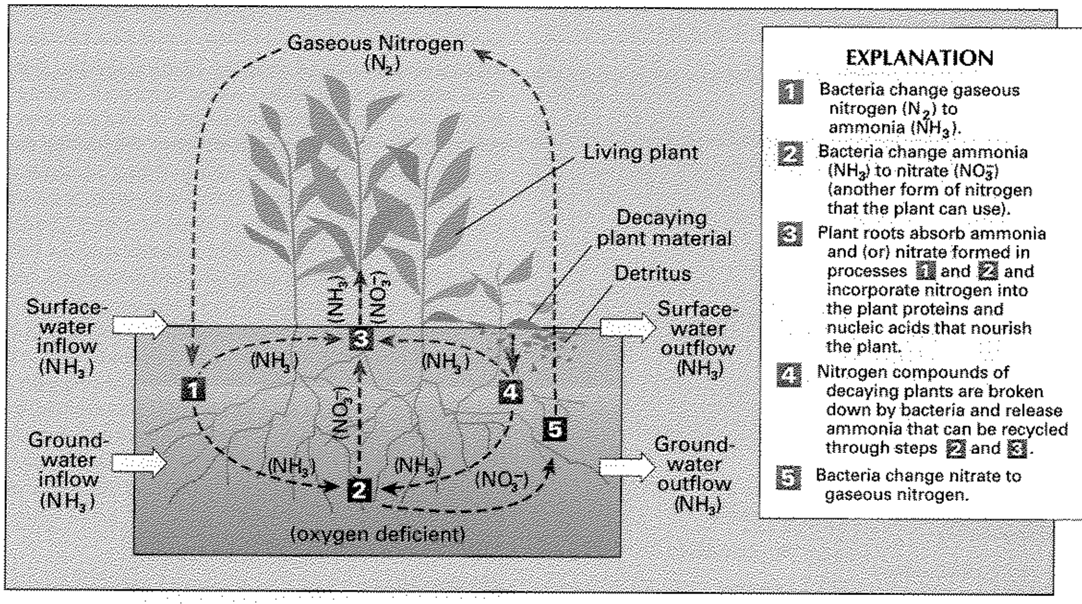

Figure 26. Simplified diagram of the nitrogen cycle in a wetland.

accumulates in wetlands creating a source of waterborne dissolved and particulate organic materials. Some materials, for example nutrients, are changed from one form to another as they pass through the wetland (fig. 26). Most stored materials in wetlands are immobilized as a result of prevailing water chemistry and hydrology, but any disturbance can result in release of those materials.

The water purification functions of wetlands are dependent upon four principal components of the wetland—substrate, water, vegetation, and microbial populations (Hammer, 1992; Hemond and others, 1987).

Substrates.—Wetland substrates provide a reactive surface for biogeochemical reactions and habitat for microbes. Wetland soils are the medium in which many of the wetland chemical transformations occur and the primary storage area of available chemicals for most plants (Mitsch and Gosselink, 1993). Organic or peat soils differ from mineral soils in their biogeochemical properties, including their ability to hold water and bind or immobilize mineral constituents.

Water.—Ground and surface waters transport solid materials and gases to the microbial and plant communities, remove the by-products of chemical and biological reactions from the wetlands, and maintain the environment in which the essential biochemical processes of wetlands occur. Flooding or soil saturation causes oxygen-deficient conditions that markedly influence many biological transformations.

Vegetation.—Wetland vegetation reduces the flow and decreases velocities of water, causing the deposition of mineral and organic particles and constituents attached to them, such as phosphorus or trace metals. Plants introduce oxygen to the generally oxygen-deficient soil environment through their roots, creating an oxidized root zone where bacterial transformations of nitrogenous and other compounds can occur (Good and Patrick, 1987). Plants also provide a surface for microbial colonization. Wetland plants remove small quantities of nutrients, trace metals, and other compounds from the soil water and incorporate them into plant tissue, which may later be recycled in the wetland through decomposition, stored as peat, or transported from the wetland as particulate matter (Boyt and others, 1977; Tilton and Kadlec, 1979; Hammer, 1992).

Microbes.—The microbial community, which includes bacteria, algae, fungi, and protozoa, is responsible for most of the chemical transformations that occur in wetlands. In order to meet their metabolic needs, microbes use up oxygen; transform nutrients, manganese, and iron; and generate methane, hydrogen sulfide gas, and carbon dioxide.

Wetlands serve as short-term or long-term sediment sinks. Floodwater spreading out across a wetland decreases in velocity, and sediments settle out and are trapped within the wetland. Some of this sediment may be transported out of the wetland during future flooding. Sediment deposition in estuarine wetlands provides a constant input that is of special importance for maintenance of wetlands acreage during periods of sea-level rise (Bricker-Urso and others, 1989).

The ability of wetlands to filter and transform nutrients and other constituents has resulted in the construction and use of artificial wetlands in the United States and other countries to treat wastewater and acid mine drainage (Hammer, 1989, 1992; Wieder, 1989). However, individual wetlands have a limited capacity to absorb nutrients and differ in their ability to do so (Tiner, 1985). A wetland's effectiveness in improving water quality depends on hydrologic patterns, amount and type of vegetation, time of year, and the constituent of concern (Zedler and others, 1985).

Estuarine Water Balance

Estuaries receive freshwater from precipitation, ground-water discharge, streamflow, and overland flow. Ground water discharges through shallow-water sediments of the estuary or through marsh soils and can affect the nutrient balance and salinity of the

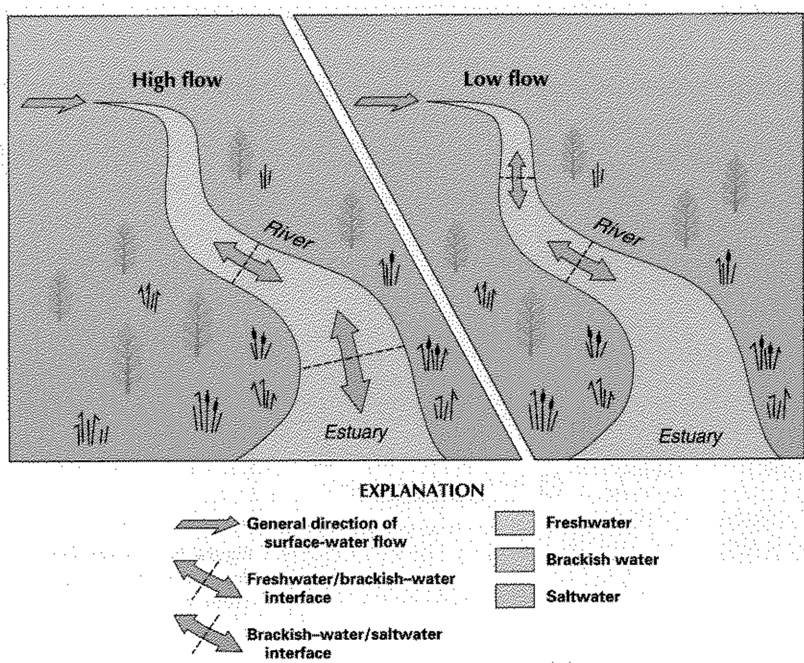

Figure 27. Movement of the freshwater-saltwater interface in an estuary during periods of high flow and during periods of low flow.

receiving waters (Valiela and others, 1978; Harvey and Odum, 1990). Estuarine salinity decreases during periods of high streamflow as the freshwater-saltwater interface moves down the estuary from the stream toward the sea (fig. 27). Estuarine salinity increases as streamflow decreases and the interface moves up the estuary. Estuarine plants and animals are well adjusted to these normal seasonal fluctuations in salinity. Water temporarily stored in flood-plain wetlands upstream from the estuary deposits sediment and nutrients, and water leaving these wetlands exports decomposition products and organic detritus to the estuary. This temporary storage of water and the concurrent decrease in flow velocity aid in controlling the timing and size of the freshwater influx to the estuary. For example, the freshwater wetlands of the Barataria Basin in Louisiana serve as a major freshwater reservoir for maintenance of favorable salinities in the brackish zone, and the major pulse of materials to the estuary coincides with the arrival of migrant fish for growth and spawning. Leaves that fall in flood-plain wetlands are broken down and enriched by microbial action and produce high-quality food for detrital based food chains in the estuary. Alterations in the timing and quality of streamflow and associated suspended particulate and dissolved material, caused by dams or artificial drainage, can alter the chemistry of coastal waters and affect the organisms that inhabit them.

Wetlands reduce the erosive forces of wind and waves.

Erosion Reduction

Wetlands reduce shoreline erosion by stabilizing sediments and absorbing and dissipating wave energy (Hammer, 1992). The ability of wetlands to stabilize and protect shorelines depends on their capacity to reduce the erosive forces of wind and waves. Beaches and shallow vegetated wetlands protect shorelines in moderate and small storms if the water does not carry excessive amounts of abrasive floating debris. Wetland vegetation decreases water velocities through friction and causes sedimentation in shallow water areas and flood-plain wetlands, thus decreasing the erosive power of the water and building up natural levees. Trees are excellent riverbank stabilizers and have been planted to reduce erosion along United States shorelines. Other wetland plants such as bulrushes, reeds, cattails, cordgrass, and mangroves can also successfully withstand wave and current action.

When vegetation is removed, streambanks collapse and channels widen and (or) deepen; removal of wetland vegetation can turn a sediment sink into a sediment source. The dissipation of erosive forces by vegetation differs from wetland to wetland and depends upon vegetative composition and root structure, sediment type, and the frequency and intensity of water contact with the bank.

SUMMARY

Wetlands are complex ecosystems in which ground water and surface water interact, but because ground water cannot be directly observed, its role in the hydrology of wetlands is sometimes more difficult to understand than that of surface water. Many wetlands owe their existence not only to poor drainage at the site but also to the discharge of ground water at the site. The hydrology of a wetland determines what functions it will perform. Each wetland is unique, but those with similar hydrologic settings generally perform similar functions.

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Technical Aspects of Wetlands

Wetlands as Bird Habitat

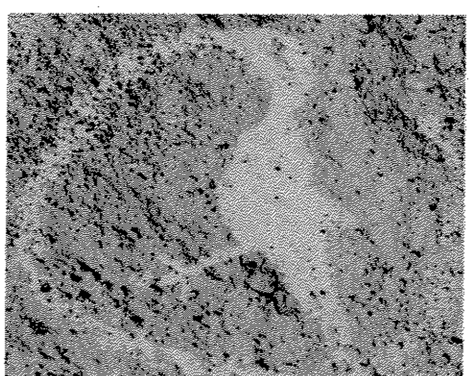
By Robert E. Stewart, Jr.[1]

Figure 28. This wetland in California is habitat for migrating snow geese. *(Photograph by James R. Nelson, California Department of Fish and Game.)*

The value of a wetland to a specific bird species is affected by the presence of surface water and the duration and timing of flooding.

One of the best known functions of wetlands is to provide a habitat for birds (fig. 28). Humans have known of the link between birds and wetlands for thousands of years. Prehistoric people drew pictures of birds and wetlands on cave walls, scratched them onto rocks, and used them in the design of artifacts (fig. 29); and Native American lore provides accounts of bird hunts in wetlands. Wetlands are important bird habitats, and birds use them for breeding, nesting, and rearing young (fig. 30). Birds also use wetlands as a source of drinking water and for feeding, resting, shelter, and social interactions. Some waterfowl, such as grebes, have adapted to wetlands to such an extent that their survival as individual species depends on the availability of certain types of wetlands within their geographic range. Other species, such as the northern pintail or the American widgeon, use wetlands only during some parts of their lives.

Wetlands occupy only a small part of the landscape that is now the conterminous United States—11 percent in 1780 and just 5 percent in 1980 (Dahl and others, 1991). Nonetheless, they are important to birds. During the past 20 years, policies and programs that encourage altering, draining, or filling of wetlands have decreased, and policies that encourage wetland conservation and restoration have increased. (See article "Wetland Protection Legislation" in this volume.) Among the wetland attributes society seeks to protect and conserve are those that benefit wildlife, particularly migratory birds. This article discusses the benefits that wetlands provide for birds and the effects of wetland losses on birds.



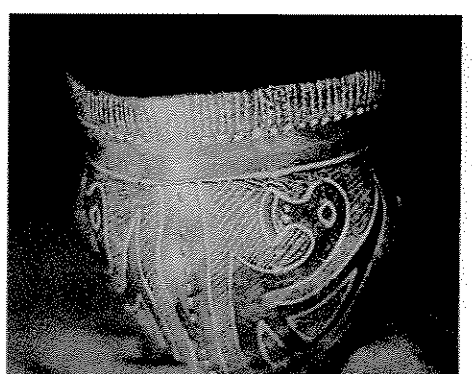


Figure 29. The importance of wetland birds to ancient people is portrayed in these two artifacts. The petroglyph at the left, created between A.D.1300 and 1650, is located at Petroglyph National Monument near Albuquerque, N. Mex. The clay "duck pot" at the right, fired between 200 B.C. and A.D. 500, was unearthed at Hopewell Culture National Historical Park, Chillicothe, Ohio. *(Photographs courtesy of the National Park Service.)*

[1] National Biological Service.

The geographic location of a wetland may determine how and when birds will use it.

Figure 30. This baby heron will be raised in a wetland environment. *(Photograph courtesy of National Biological Service.)*

Figure 31. The raccoon is a wetland predator that eats eggs and preys on birds. *(Photograph courtesy of National Biological Service.)*

Figure 32. The American alligator is an effective and voracious predator of wetland birds in the South. *(Photograph courtesy of National Biological Service.)*

Figure 33. This American bittern, with its protective coloration, is well hidden in the vegetation. *(Photograph by James Leopold, National Biological Service.)*

WETLAND FACTORS THAT AFFECT BIRDS

The relation between wetlands and birds is shaped by many factors. These include the availability, depth, and quality of water; the availability of food and shelter; and the presence or absence of predators. Birds that use wetlands for breeding depend on the physical and biological attributes of the wetland. Birds have daily and seasonal dependencies on wetlands for food and other life-support systems.

The value of a wetland to a specific bird species is affected by the presence of surface water or moist soils and the duration and timing of flooding. Water might be present during the entire year, during only one or more seasons, during tidal inundation, or only temporarily during and after rainfall or snowmelt. At times water might not be present at the land surface, but might be close enough to the land surface to maintain the vegetation and foods that are needed by birds. Birds may use wetlands located in depressions in an otherwise dry landscape, along streams, or in tidally influenced areas near shorelines.

The availability or influence of water is a very important wetland feature to birds. It is not, however, the only feature that determines if birds will be present, how birds use the wetland, or how many kinds or numbers of birds may use the wetland. Other determining physical or biological factors include water depth and temperature, presence or absence of vegetation, patchiness or openness of vegetation, type of vegetation, foods, water chemistry, type of soils, and geographic or topographic location. Any variations in any of these wetland features will cause subtle, but distinct, differences in bird use.

Wetlands provide food for birds in the form of plants, vertebrates, and invertebrates. Some feeders forage for food in the wetland soils, some find food in the water column, and some feed on the vertebrates and invertebrates that live on submersed and emergent plants. Vegetarian birds eat the fruits, tubers, and leaves of wetland plants. Water temperatures influence food production. Invertebrate production in the water column may ultimately depend on water temperature and the ability of a wetland to produce algae. Cold water might not be a hospitable environment for small animals and plants that some wetland birds eat. However, water that is too warm also might not produce foods that some birds prefer.

Wetland vegetation provides shelter from predators and from the weather. The presence or absence of shelter may influence whether birds will inhabit a wetland or a nearby upland area. Predators are likely to abound where birds concentrate, breed, or raise their young. Wetlands form an important buffer or barrier to land-based predators and reduce the risk of predation to nesting or young birds. However, some predators, such as the raccoon (fig. 31), are well adapted to both wetland and upland environments, and take large numbers of both young and nesting birds. Mink forage for nesting or sleeping birds along the edges and interiors of wetlands. Other animals, such as the snapping turtle, the alligator (fig. 32), or the large-mouthed bass, are effective water-based predators of young birds, particularly young waterfowl. Snakes take their toll as well. Many bird species that are highly adapted to feeding in a wetland

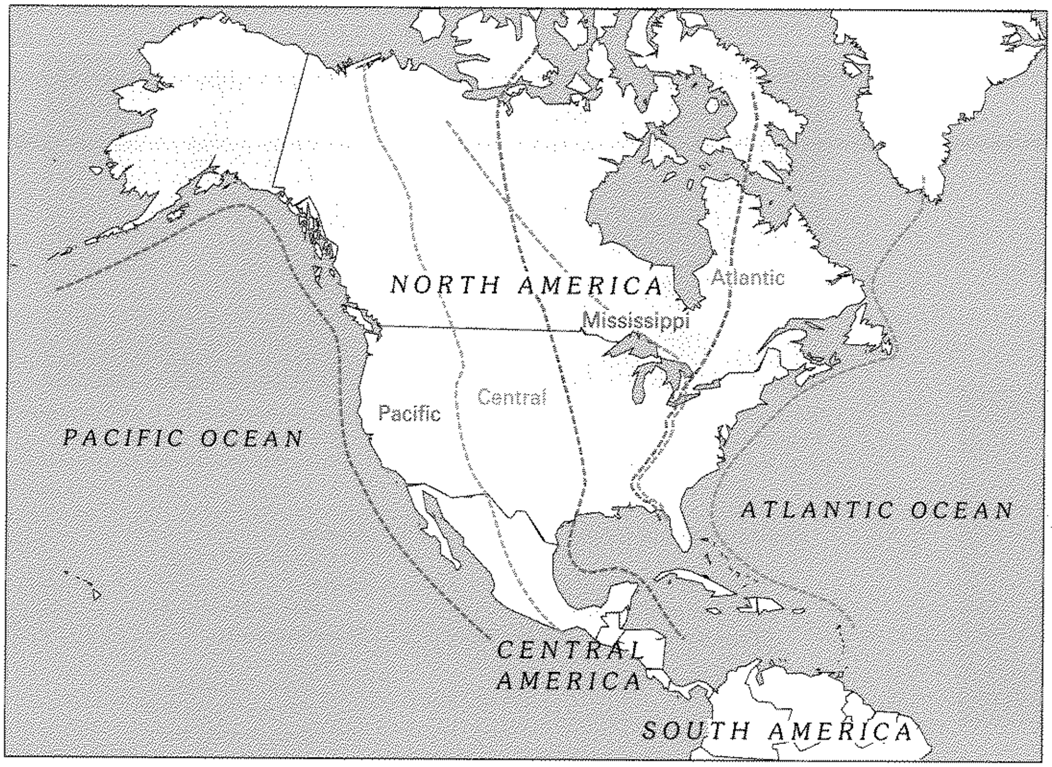


Figure 34. Major flyway corridors for migrating birds in the Western Hemisphere. *(Source: From U.S. Fish and Wildlife Service files.)*

environment also have genetic adaptations that lower their risk of becoming prey. One such example is the bittern (fig. 33), which has excellent protective coloration. The same vegetation that hides birds from predators also provides some shelter from severe weather. In spring, during cold and stormy weather, waterfowl such as canvasback ducks protect their young in the shelter of a marsh that is almost impenetrable to wind.

The geographic location of a wetland may determine how and when birds will use it or use adjacent habitat. In the northern latitudes or at high altitudes, some wetlands are covered with ice in the winter and are temporarily "out of service" for birds adapted to a water environment, but emergent vegetation might still offer shelter and food for some species. Birds that eat fish, aquatic invertebrates, or submersed vegetation cannot forage for food because of the ice cover. Some wetlands are on the migration path of waterfowl and other migratory birds and provide stopover locations for traveling birds (fig. 34). These birds might feed in agricultural fields during the day and return to the shelter of wetlands during the night.

The "prairie potholes" are a special type of wetland, found in the north-central part of the United States. These potholes are an example of a wetland type that is important to migrating waterfowl. Here the timing and duration of inundation and the salinity of the water are important factors in the production of plants and invertebrates used by birds. These, and many other wetland characteristics, are influenced by a number of things:

- Water-level fluctuations throughout the year, in response to rainfall and snowmelt, that maintain wetland zones such as wet meadows and marshes
- Short-term (years) and long-term (decades) climatic trends that cycle wetlands between a wet and dry state
- Interaction of surface and ground water
- Interaction of ground water with rocks and soils that influence salinity and other wetland water chemistry

THE IMPORTANCE OF WETLANDS TO BIRDS

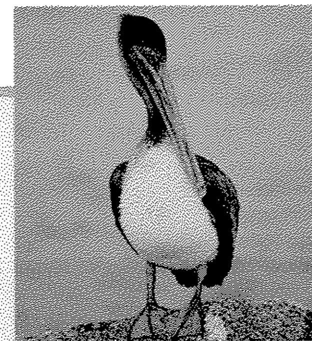
Because of the great variety of wetlands, bird adaptation to and use of wetland environments differs greatly from species to species. Birds' use of wetlands during breeding cycles ranges widely. Some birds depend on wetlands almost totally for breeding, nesting, feeding, or shelter during their breeding cycles. Birds that need functional access to a wetland or wetland products during their life cycle, especially during the breeding season, can be called "wetland dependent" (table 5). Other birds use wetlands only for some of their needs, or they might use both wetland and upland habitats. Of the more than 1,900 bird species that breed in North America, about 138 species in the conterminous United States are wetland dependent (American Ornithologists'Union, 1983).

Many bird species use forested wetlands as well as forested uplands, feeding on the abundant insects associated with trees (fig. 35). These birds are not de-

Table 5. Wetland-dependent breeding birds of the conterminous United States, including federally endangered or threatened species and subspecies[1, 2]

[Source: Data from American Ornithologists' Union, 1983; Niering, 1988; Ehrlich and others, 1992]

Green-backed heron. *(Photograph by Thomas A. Muir, National Biological Service.)*



This brown pelican is an endangered species. *(Photograph by Thomas A. Muir, National Biological Service.)*

Roseate spoonbill at a nesting rookery. *(Photograph by Ronald F. Paille, U.S. Fish and Wildlife Service.)*

Snowy egret on the nest. *(Photograph by David Hall, U.S. Fish and Wildlife Service.)*

Cranes and their allies
- Yellow rail
- Black rail
  - [3] California black rail
- Clapper rail
  - [4] Light-footed clapper rail
  - [4] California clapper rail
  - [4] Yuma clapper rail
- King rail
- Virginia rail
- Sora rail
- Purple gallinule
- Common moorhen
- American coot
- Limpkin
- Sandhill crane (facultative)
  - [4] Mississippi sandhill crane
  - [4] Whooping crane

Cuckoos
- Mangrove cuckoo

Grebes
- Least grebe
- Pied-billed grebe
- Horned grebe
- Red-necked grebe
- Eared grebe
- Western grebe

Herons and their allies
- American bittern
- Least bittern
- Great blue heron
  - [4] Florida great white heron
- Great egret
- Snowy egret
- Little blue heron
- Tricolored heron
- Reddish egret
- Cattle egret
- Green-backed heron
- Black-crowned night heron
- Yellow-crowned night heron
- White ibis
- Glossy ibis
- White-faced ibis
- Roseate spoonbill
- [4] Wood stork

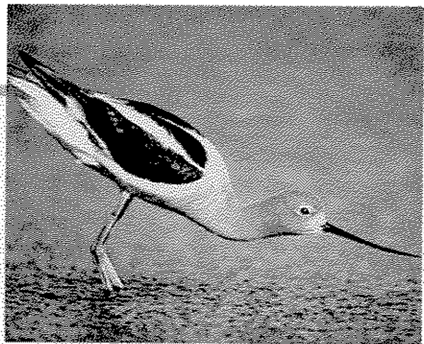
Kingfishers
- Belted kingfisher

Loons
- Common loon

Owls
- Short-eared owl

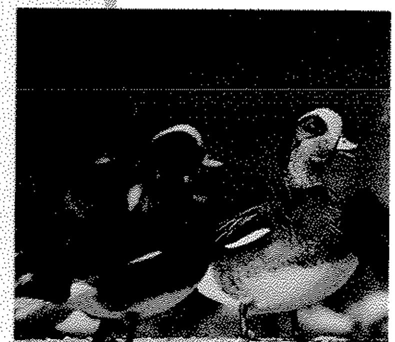
Perching birds
- Flycatchers
  - Alder flycatcher
  - Willow flycatcher
  - Gray flycatcher
- Swallows
  - Tree swallow
  - Northern rough-winged swallow
  - Bank swallow
- Wrens
  - Sedge wren
  - Marsh wren
- Dippers
  - American dipper
- Vireos
  - Black-whiskered vireo
- Warblers
  - [4] Bachman's warbler
  - Prothonotary warbler
  - Swainson's warbler
  - Northern waterthrush
  - Louisiana waterthrush
  - Connecticut warbler
  - Common yellowthroat
- Sparrows
  - Savannah sparrow
    - [3] Belding's savannah sparrow
  - LeConte's sparrow
  - Sharp-tailed sparrow
  - Seaside sparrow
    - [5] Dusky seaside sparrow
    - [4] Cape sable sparrow
  - Lincoln's sparrow
  - Swamp sparrow
- Blackbirds
  - Red-winged blackbird
  - Tricolored blackbird
  - Yellow-headed blackbird
  - Great-tailed grackle
  - Boat-tailed grackle

Pelicans and their allies
- American white pelican
- Brown pelican
  - [4] California brown pelican



The American avocet. *(Photograph courtesy of National Biological Service.)*

Colony of sandwich terns on the Chandeleur Islands, La. *(Photograph courtesy of National Biological Service.)*



These American wigeons will spend part of their lives in a wetland habitat and part in an upland environment. *(Photograph courtesy of National Biological Service.)*

Male wood ducks. *(Photograph by Thomas A. Muir, National Biological Service.)*

Double-crested cormorant
Olivaceous cormorant
Anhinga

Shorebirds, Gulls, and Alcids
Plovers, surfbirds, and turnstones
Snowy plover
Wilson's plover
[4] Piping plover
Killdeer (facultative)
Oystercatchers
American oystercatcher
American black oystercatcher
Avocets and stilts
Black-necked stilt
American avocet
Sandpipers and allies
Willet
Spotted sandpiper
Marbled godwit
Common snipe
American woodcock
[4] Eskimo curlew
Phalarope
Wilson's phalarope
Gulls and terns
Laughing gull
Franklin's gull
Little gull
Heerman's gull (facultative)
Ring-billed gull
California gull
Herring gull
Western gull
Great black-backed gull
Gull-billed tern
Caspian tern
Royal tern
Elegant tern
Sandwich tern
[4] Roseate tern
Common tern
Forster's tern
Least tern
[4] California least tern
Sooty tern
Black tern
Skimmers
Black skimmer

Vultures, Hawks, and Falcons
Osprey
American swallow-tailed kite
[4] Everglade snail kite
[4] Bald eagle
Northern harrier
Peregrine falcon
[4] American peregrine falcon

Waterfowl
Swans
Trumpeter swan
Geese
Canada goose
Tree ducks
Fulvous whistling duck
Black-bellied whistling duck
Surface feeding ducks
Wood duck
Green-winged teal
American black duck
Mottled duck
Mallard
Northern pintail
Blue-winged teal
Cinnamon teal
Northern shoveler
Gadwall
American wigeon
Bay ducks
Canvasback
Redhead
Ring-necked duck
Greater scaup
Lesser scaup
Sea ducks
Harlequin duck
White-winged scoter
Common goldeneye
Barrow's goldeneye
Bufflehead
Mergansers
Hooded merganser
Common merganser
Red-breasted merganser
Stiff-tailed ducks
Ruddy duck

[1] Table arranged by group, species, and subspecies. To facilitate the use of this table, order of presentation differs from that normally used.
[2] Does not include oceanic or pelagic birds.
[3] Candidate for placement on endangered species list.
[4] Federally endangered or threatened wetland-dependent bird species or subspecies.
[5] Became extinct in 1987.

Figure 35. Prothonotary warblers feed on insects of forested wetlands and uplands alike. *(Photograph courtesy of National Biological Service.)*

pendent on wetlands because they use both habitats equally well. Some birds, such as wood ducks, are found primarily in forested wetlands and are dependent on this wetland type.

Many migratory birds are wetland dependent, using wetlands during their migration and breeding seasons. Migratory birds may spend the winter in wetlands in the Southern United States, or farther south (fig. 34). Throughout winter, these birds use southern wetlands for food and nutrients to sustain them for their return trip north and the breeding season.

Not all wetlands are of equal value to waterfowl and other birds. An inventory in the conterminous United States during the early 1950's showed that of 74.4 million acres of wetlands, 8.8 million acres had a high value for waterfowl, 13.6 million acres were of moderate value, 24.1 million acres were of low value, and 27.9 million acres were of negligible value (Shaw and Fredine, 1956, p. 17). These categories were identified on a State-by-State basis and were ranked according to use by waterfowl, with "high" being most used. The primary focus of this inventory was waterfowl; thus these rankings might not reflect wetland values for other birds. Also, the inventory was for only natural wetlands that had been little altered by human activities. The three areas of highest value are the Mississippi River corridor southward from Cairo, Ill., and westward along the Texas gulf coast; the entire east coast from Maine southward through most of Florida; and the northern Midwest.

Widespread draining and altering of wetlands has affected bird populations.

THE INFLUENCE OF WETLANDS ON WATERFOWL POPULATIONS

Considerable research has increased the understanding of wetlands' influence on the numbers of waterfowl that breed and their breeding success. However, the relation between wetlands and the population and propagation of various waterfowl species is not well understood. This relation depends on: (1) the number of wetlands in the area; (2) the wetlands' size and water depth; (3) whether the wetlands hold open water in the early spring or through late August; (4) the climate; and (5) the species of bird and the bird's adaptations to wetlands.

In the prairie pothole region in the late 1970's, for example, as the number of wetlands in an area increased, populations of dabbling ducks increased, but at a ratio of less than 1:1 (fig. 36). In the past 20 years, the duck-pothole ratio has decreased, possibly due to decreases in upland cover and increases in predation. Bellrose (1977) also found waterfowl densities and propagation to be related to the number of wetlands per square mile; generally, waterfowl densities and propagation increased as the number of wetlands increased. However, he found that mallard production decreased when the number of wetlands exceeded 12 per square mile.

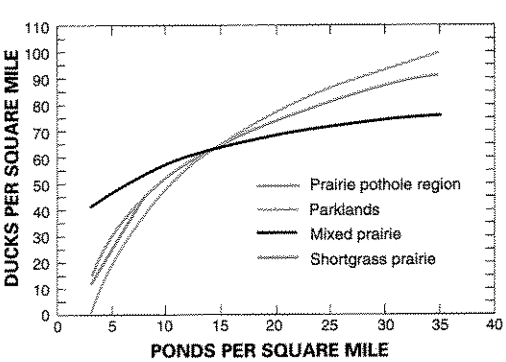


Figure 36. The relation of pond density increase to number of ducks. (Source: After Bellrose, 1977.)

Different waterfowl species adapt to different wetland types, inhabit different geographic areas, and nest at different times. The relation of many other species of birds to wetlands are undoubtedly just as complex.

EFFECTS OF WETLAND LOSS AND DEGRADATION ON BIRDS

About one-third of North American bird species use wetlands for food, shelter, and (or) breeding (Kroodsma, 1979). Thus, widespread draining and altering of wetlands has affected bird populations. Because most of the wetland drainage and alteration occurred between the 1930's and 1950, before scientific estimates of bird populations began, most estimates of population declines are inferred. Before the passage of the Migratory Bird Treaty Act in 1918, the reduction in waterfowl populations was blamed largely on excessive hunting and wetland drainage (Day, 1959). However, since 1930 most of the reduction has been attributed to the loss or degradation of wetlands (Bellrose and Trudeau, 1988) and the loss of suitable upland habitats that surround wetlands.

For most wetland-dependent birds, habitat loss in breeding areas translates directly into population losses. As wetlands are destroyed, some birds may move to other less suitable habitats, but reproduction tends to be lower and mortality tends to be higher. Hence, the birds that breed in these poorer quality habitats will not contribute to a sustainable population through the years (Pulliam and Danielson, 1991).

About one-half of the 188 animals that are federally designated as endangered or threatened are wetland dependent (Niering, 1988). Of these, 17 are bird species or subspecies (table 5). These birds are categorized as endangered or threatened because their populations are so low that the risk of their extinction is real and immediate. The circumstances that cause each species or subspecies to be endangered differ greatly.

Wetland loss due to draining, filling, or altering of surface-water and ground-water flow is a concern to many people. Wetland degradation also has a substantial effect on birds. Although wetland degradation is a serious problem, it is one that is more subtle and less understood than wetland losses. Degradation can take many forms:

- Amounts and periodicity of water supplies can be altered
- The quality of water flowing into and through a wetland can be modified
- The flows of sediments or freshwater to coastal marshes can be reduced
- Water levels can be stabilized in wetlands that otherwise would undergo beneficial drawdowns or water-table fluctuations
- Wetland vegetation may be altered by harvesting or by introducing exotic species, making it of little or no value to wetland-dependent birds

An example of wetland degradation is found in the Chesapeake Bay region. Nutrients and sediments entering the bay from agricultural, urban, and industrial areas have caused increased algal blooms, decreased invertebrate production, and lowered oxygen levels. This degradation has reduced the acreage of seagrasses that form an important link in the food chain for invertebrates, fish, and wetland-dependent birds. The decline in the canvasback duck population in this area is thought to be directly related to the decline in seagrasses.

Chemicals and sediments that move from agricultural areas into wetlands are two of the most pervasive sources of degradation. The shift in human populations from inland areas to coastal areas of the United States has caused problems in coastal wetlands through overloaded sewage treatment systems. The large and growing volume of industrial wastes that enter ground- and surface-water supplies also threatens to degrade wetlands. These threats, combined with habitat destruction, have a net negative effect on the population of wetland birds. Thus, if the amount and quality of wetland habitat is substantially reduced, populations of wetland-dependent birds in the area also can be expected to decrease.

SOME EFFORTS TO PRESERVE WETLAND BIRD HABITATS

Many people believe that ownership or management of wetlands by public conservation agencies, such as the U.S. Fish and Wildlife Service, and by private organizations, such as the Nature Conservancy or the National Audubon Society, offers the best assurance that the highest value wetlands will be maintained for future generations. (A discussion of the agencies and organizations that participate in management and conservation of wetlands in each State can be found in the State Summaries section of this report.)

A few early concerns for wetlands important to waterfowl are reflected in the creation of the first national wildlife refuge and in the establishment of the Federal Duck Stamp program. The first national wildlife refuge was created in 1903, by President Theodore Roosevelt, to protect a wetland—Pelican Island, Florida (U.S. Fish and Wildlife Service, [1995]). Concern for the loss of waterfowl led to the Federal Duck Stamp program that began in 1934 (Mitsch and Gosselink, 1993) and continues today. Duck stamps are sold to waterfowl hunters to provide money for the purchase or preservation of wetlands (fig. 37).

Several international treaties are partly responsible for much of the formal wetland protection in this country—the Migratory Bird Treaty and the Convention on Wetlands of International Importance especially as Waterfowl Habitat. "In 1918, the U[nited] S[tates] passed into law the Migratory Bird Treaty Act, ratifying a treaty with Great Britain, on behalf of Canada, that recognized the conservation responsibilities for more than 800 species of migratory birds shared by the two countries" (U.S. Fish and Wildlife Service, [1995]). Subsequent to that act, the United States developed the National Wildlife Refuge System consisting of 500 reserves—many of which are wetlands important to birds—comprising more than 90 million acres (fig. 38). The system has the highest ratio of wetlands to dry land in public ownership. The National Park Service manages the Everglades National Park and several preserves that also have high ratios of wetlands to dry lands.

The Convention on Wetlands of International Importance especially as Waterfowl Habitat, more commonly known as the "Ramsar Convention" is an intergovernmental treaty for international cooperation for the conservation of wetland habitats. The U.S. Fish and Wildlife Service is responsible for implementation of the convention in the United States. A "List of Wetlands of International Importance" has been developed by the convention. Sites on this list are known as "Ramsar Sites" and are wetlands that convention members have a special obligation to preserve. There are 15 Ramsar sites in this country (fig. 38).

Figure 37. The purchase of duck stamps provides funds for the acquisition or protection of wetlands important to waterfowl. *(Source: U.S. Fish and Wildlife Service.)*

About one-half of the 188 animals that are federally designated as endangered or threatened are wetland dependent.

SUMMARY AND CONCLUSIONS

Human activities have caused shifts in wetland-dependent bird populations since European settlement of the United States, especially since the beginning of the 20th century. Many acres of wetlands were drained between the 1930's and 1950, well before any of the national bird surveys were begun. As a result, it is not possible to accurately determine the effects of habitat destruction on long-term wetland bird populations.

It is apparent that there have been many changes in the distribution and numbers of wetland birds. Wetlands on breeding, migratory, or wintering areas are all important to sustain bird populations. As the wetland habitats in these areas are drained or altered, the ability of these areas to sustain bird populations decreases. Each species of wetland-dependent bird has a unique and complex set of needs for wetland

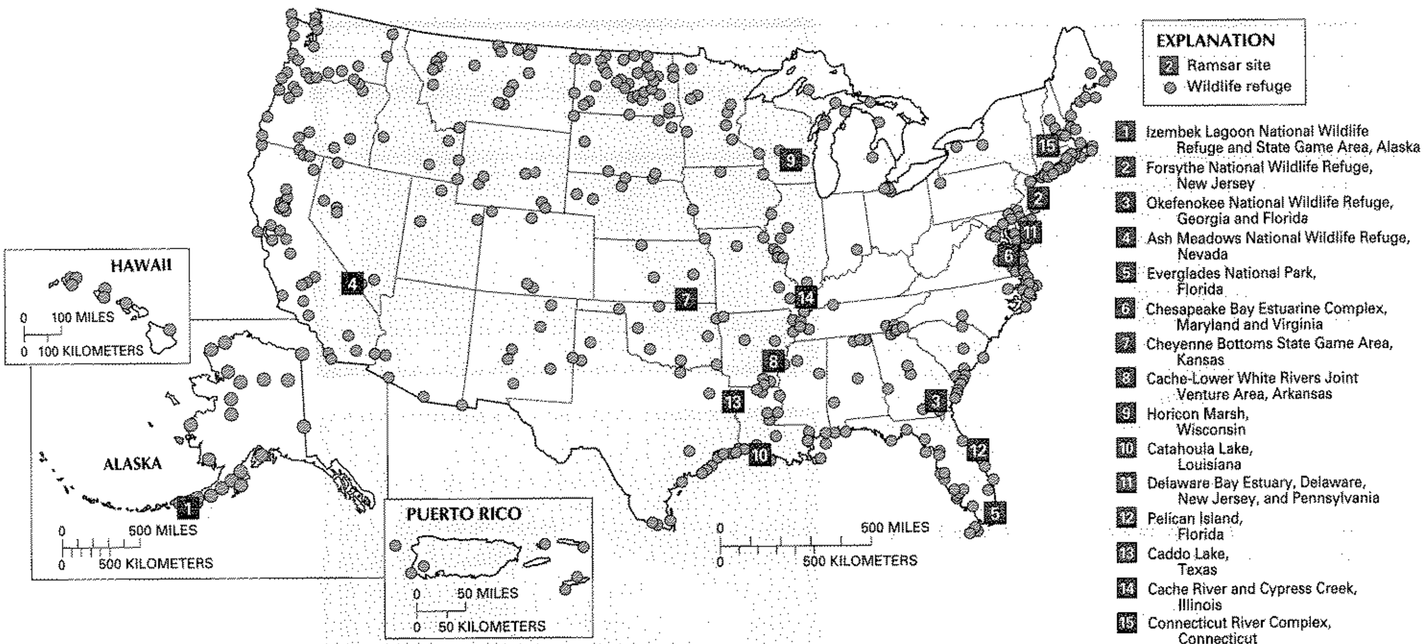


Figure 38. Location of National Fish and Wildlife Refuge System reserves and Ramsar sites in the United States. *(Source: U.S. Fish and Wildlife Service, 1993, [1995].)*

habitats that makes it difficult to generalize about how loss or degradation of wetlands affects bird populations. It seems reasonable to expect, however, that as the numbers of wetlands in a region decline, so too will the numbers of wetland-dependent birds.

In some parts of the United States, extensive wetland losses have displaced birds from large areas. Continued wetland losses probably will cause continued losses of wetland birds. However, recent recognition of the wetland values, and the effects of their losses, have provided incentives to maintain and restore wetlands.

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Wetland Management and Research

Wetland Protection Legislation

By Todd H. Votteler[1] and Thomas A. Muir[2]

The people of the United States have begun to recognize that wetlands have numerous and widespread benefits. However, many of the goods and services wetlands provide have little or no market value. Because of this, the benefits produced by wetlands accrue primarily to the general public. Therefore, the Government provides incentives and regulates and manages wetland resources to protect the resources from degradation and destruction. Other mechanisms for wetland protection include acquisition, planning, mitigation, disincentives for conversion of wetlands to other land uses, technical assistance, education, and research.

Although many States have their own wetland regulations, the Federal Government bears a major responsibility for regulating wetlands. The five Federal agencies that share the primary responsibility for protecting wetlands include the Department of Defense, U.S. Army Corps of Engineers (Corps); the U.S. Environmental Protection Agency (EPA); the Department of the Interior, U.S. Fish and Wildlife Service (FWS); the Department of Commerce, National Oceanic and Atmospheric Administration (NOAA); and the Department of Agriculture, Natural Resources Conservation Service (NRCS) (formerly the Soil Conservation Service). Each of these agencies has a different mission that is reflected in the implementation of the agency's authority for wetland protection. The Corps' duties are related to navigation and water supply. The EPA's authorities are related to protecting wetlands primarily for their contributions to the chemical, physical, and biological integrity of the Nation's waters. The FWS's authorities are related to managing fish and wildlife—game species and threatened and endangered species. Wetland authority of NOAA lies in its charge to manage the Nation's coastal resources. The NRCS focuses on wetlands affected by agricultural activities.

States are becoming more active in wetland protection. As of 1993, 29 States had some type of wetland law (Want, 1993). Many of these States have adopted programs to protect wetlands beyond those programs enacted by the Federal Government. As more responsibility is delegated from the Federal Government to the States, State wetland programs are gaining in importance. Thus far, States have devoted more attention to regulating coastal wetlands than inland wetlands. The most comprehensive State programs include those of Connecticut, Rhode Island, New York, Massachusetts, Florida, New Jersey, and Minnesota (Mitsch and Gosselink, 1993). Many of these States regulate those activities affecting wetlands that are exempt from the Clean Water Act, Section 404 program. (For more information on specific State wetland protection programs, see the State Summary section of this volume.)

Despite the current recognition of wetland benefits, many potentially conflicting interests still exist, such as that between the interests of landowners and the general public and between developers and conservationists. Belated recognition of wetland benefits and disagreement on how to protect them has led to discrepancies in local, State, and Federal guidelines. Discrepancies in Federal programs are apparent in table 6, which shows programs that encourage conversion of wetlands and those that discourage conversion of wetlands. Conflicting interests are the source of much tension and controversy in current wetland protection policy. Although attempts are being made to reconcile some of these differences, many policies will have to be modified to achieve consistency.

Despite all the government legislation, policies, and programs, wetlands will not be protected if the regulations are not enforced. Perhaps the best way to protect wetlands is to educate the public of their benefits. If the public does not recognize the benefits of wetland preservation, wetlands will not be preserved. Protection can be accomplished only through the cooperative efforts of citizens.

If the public does not recognize the benefits of wetland preservation, wetlands will not be preserved.

FEDERAL WETLAND PROTECTION PROGRAMS AND POLICIES

The Federal Government protects wetlands directly and indirectly through regulation, by acquisition, or through incentives and disincentives as described in table 6. Section 404 of the Clean Water Act is the primary vehicle for Federal regulation of some of the activities that occur in wetlands. Other programs, such as the "Swampbuster" program and the Coastal Management and Coastal Barriers Resources Acts, provide additional protection. Coastal wetlands generally benefit most from the current network of statutes and regulations. Inland wetlands are more vulnerable than coastal wetlands to degradation or loss because current statutes and policies provide them less comprehensive protection. Several of the major Federal policies and programs affecting wetlands are discussed in the following few pages. Also discussed are some of the States' roles in Federal wetland policies.

The Clean Water Act

The Federal Government regulates, through Section 404 of the Clean Water Act, some of the activities that occur in wetlands. The Section 404 program originated in 1972, when Congress substantially amended the Federal Water Pollution Control Act and created a Federal regulatory plan to control the discharge of dredged or fill materials into wetlands and other waters of the United States. Discharges are commonly associated with projects such as channel construction and maintenance, port development, fills to create dry land for development sites near the water, and water-control projects such as dams and levees. Other kinds of activities, such as the straightening of river channels to speed the flow of water downstream

[1] University of Texas.
[2] National Biological Service.

Table 6. Federal programs that have significant effects on wetlands in the United States. ***A***, Regulations encouraging wetland conversion. ***B***, Regulations discouraging or preventing wetland conversion. ***C***, Acquisitions discouraging or preventing wetland conversion. ***D***, Other policies and programs preventing or discouraging wetland conversion.

[Abbreviations: AFA, All Federal Agencies; ASCS, Agricultural Stabilization and Conservation Service; BLM, Bureau of Land Management; Corps, U.S. Army Corps of Engineers; CWS,Canadian Wildlife Service; DOD, Department of Defense; DOE, Department of Energy; DOI, Department of the Interior; DOT, Department of Transportation;

A, ENCOURAGING WETLAND CONVERSION

Program or Act	Implementing agency	Effect of program
Executive Order 12630, Constitutional Takings	AFA	Provides a review process for agencies to protect against unintentional "takings" of private property.
Federal-Aid Highway Act of 1968	DOT	Highway construction can affect wetlands at every stage. Wetlands are often prime sites for highways.
Federal Crop Insurance	USDA	Indirectly encourages farmers to place frequently inundated areas, including wetlands, into production.
Federal Livestock Grazing	USFS, BLM	Overgrazing promotes the loss of riparian habitat.
Flood Control Act of 1944 (P.L. 78–534)	Corps	Authorized various flood-control projects resulting in wetland destruction.
National Flood Insurance Program	FEMA	Encourages development in flood plains, which contain wetlands, by providing low-cost Federal insurance.
Payment-in-Kind (PIK) Program	USDA	Indirectly encourages farmers to place previously unfarmed areas, including wetlands, into production.
Small Reclamation Projects Acts of 1956 (70 Stat. 1044)	DOI	Encourages State and local participation in small western reclamation projects, which can destroy riparian habitat.
Surface Mining Control and Reclamation Act (P.L. 95–87), (1977)	DOI	Establishes a program for regulating surface mining and reclaiming coal-mined lands, including wetlands, under the Office of Surface Mining, Reclamation, and Enforcement.
Surface Transportation Revenue Act of 1991 (P.L. 102–240)	DOT	Transportation projects directly and indirectly destroy wetlands.
U.S. Tax Code	IRS	Encourages farmers to drain and clear wetlands through tax deductions and credits for development activities.
Water Resources Development Act of 1976, 1986, 1988, 1990 (P.L.'s 94–587, 99–662, 100–676, 101–640)	Corps	Water development projects directly and indirectly destroy wetlands.

B, DISCOURAGING OR PREVENTING WETLAND CONVERSION—*Regulations*

Program or Act	Implementing agency	Effect of program
Comprehensive Environmental Response Compensation and Liability Act (Superfund) (P.L. 96–510) (1980)	AFA	Establishes liability of the U.S. Government for damages to natural resources over which the U.S. has sovereign rights. Requires the President to designate Federal officials to act as trustees for natural resources, and to conduct natural resource damage assessments.
* Coastal Barriers Resources Act (P.L. 96–348) (1982)	NOAA	Designates various undeveloped coastal barrier islands for inclusion in the Coastal Barrier Resources System. Designated areas are ineligible for Federal financial assistance that may aid development.
* Coastal Zone Management Act (P.L. 92–583) (1972)	NOAA	Provides Federal funding for wetlands programs in most coastal States, including the preparation of coastal zone management plans.
Estuary Protection Act (P.L. 90–454) (1968)	DOI	Authorized the study and inventory of estuaries, and the Great Lakes, and provided for management of designated estuaries between DOI and the States.
* Federal Water Pollution Control (P.L. 92–500) (*Clean Water Act*) Section 404 (1972)	Corps, EPA FWS, NMFS	Regulates many activities that involve the disposal of dredged and fill materials in waters of the United States, including many wetlands.
Federal Water Project Recreation Act (P.L. 89–72) (1965)	DOI, Corps	Recreation and fish and wildlife enhancement must be considered by Federal water projects. Authorizes Federal funds for acquiring land for waterfowl refuges.
Fish and Wildlife Coordination Act of 1956	DOI	Authorizes the development and distribution of fish and wildlife information and the development of policies and procedures relating to fish and wildlife.
Migratory Bird Conservation Act (45 Stat. 1222) (1929)	FWS	Established a commission to approve the acquisition of migratory bird habitat.
National Wildlife Refuge Acts (numerous Acts)	FWS	Numerous statutes establish refuges, many of which contain significant wetland acreage.
National Environmental Policy Act of 1969 (P.L. 91–190)	AFA	Requires the preparation of an environmental impact statement of all major Federal actions significantly affecting the environment.
Ramsar Convention (Treaty), adopted 1973, enforced from 1975	FWS	Convention maintains a list of wetlands of international importance and encourages the wise use of wetlands.
Rivers and Harbors Act of 1938 (52 Stat. 802)	Corps	Provides that "due regard" be given to wildlife conservation in planning Federal water projects.
Rivers and Harbors Appropriation Act of 1899, Section 10 of the (30 Stat. 1151)	Corps	Prohibits the unauthorized obstruction or alteration of navigable waters.
Watershed Protection and Flood Prevention Act (68 Stat. 666) (1954)	FWS, NRCS	Authorizes the FWS to investigate wildlife conservation on NRCS small watershed projects.
Wild and Scenic Rivers Act, (P.L. 90–542) (1968)	DOI, USDA	Protects designated river segments from damming and other alterations without a permit.
Wilderness Act of 1964 (78 Stat. 890)	DOI, USDA	Requires review of Federal lands for inclusion in the National Wilderness Preservation System.

* Discussed in text.

Table 6 —Continued.

[Abbreviations—Continued. EPA, U.S. Environmental Protection Agency; FEMA, Federal Emergency Management Agency; FERC, Federal Energy Regulatory Commission; FmHA, Farmer's Home Administration; FWS, U.S. Fish and Wildlife Service; GSA, General Services Administration; IRS, Internal Revenue Service; NMFS, National Marine Fisheries Service; NOAA, National Oceanic and Atmospheric Administration; NPS, National Park Service; NRCS, Natural Resources Conservation Service; USCG, U.S. Coast Guard; USDA, U.S. Department of Agriculture; USFS, U.S. Forest Service]

C, DISCOURAGING OR PREVENTING WETLAND CONVERSION—*Acquisitions*

Program or Act	Implementing agency	Effect of program
Coastal Wetland Planning, Protection and Restoration Act (P.L. 101–646) (1990)	Corps, FWS EPA, NMFS	Provides for interagency wetlands restoration and conservation planning and acquisition in Louisiana, other coastal States, and the Trust Territories.
Emergency Wetlands Resources Act of 1986 (P.L. 99–645)	FWS	Pays debts incurred by FWS for wetlands acquisition, and provides additional revenue sources.
Federal Aid in Wildlife Restoration Act (1937) (Ch. 899, 50 Stat.917)	FWS	Provides grants to States for acquiring, restoring, and maintaining wildlife areas.
Fish and Wildlife Conservation Act (P.L. 96–366) (1980)	FWS	Identifies land and water in the Western Hemisphere critical for migratory nongame birds.
Land and Water Conservation Fund Act (1964) (P.L. 88–578)	FWS, NPS	Acquires wildlife areas.
Lea Act(62 Stat. 238) (1948)	FWS	Authorizes the acquiring and developing of various waterfowl management areas in California.
Migratory Bird Hunting and Conservation Stamps (1934) (Ch. 71, 48 Stat. 452)	FWS	Acquires wetland easements using revenues from fees paid by hunters for duck stamps.
North American Waterfowl Management Plan (1986)	FWS, CWS	Establishes a plan for managing waterfowl resources by various methods, such as acquiring wetlands.
North American Wetlands Conservation Act (1989) (P.L. 101–233)	FWS	Encourages public/private partnerships by providing matching grants to organizations for protecting, restoring, or enhancing wetlands.
Surface Transportation Revenue Act of 1991 (P.L. 102–240)	DOT	Authorizes funding for wetland mitigation banks for State departments of transportation.
Transfer of Certain Real Property for Wildlife Conservation Purposes Act (62 Stat. 240) (1948)	GSA, DOI	Allows the GSA to transfer property to DOI, or States, for wildlife conservation.
U.S. Tax Code Tax Reform Act of 1986 (P.L. 99–514)	IRS	Provides deductions for donors of wetlands and to some nonprofit organizations.
Water Bank Act (1970) (P.L. 91–559)	ASCS	Leases wetlands and adjacent uplands from farmers for waterfowl habitat for 10-year periods.
Wetlands Loan Act (1961) (P.L. 87–383)	FWS	Provides interest-free loans for wetland acquisition and easements.

D, DISCOURAGING OR PREVENTING WETLAND CONVERSION—*Other Policies and Programs*

Program or Act	Implementing agency	Effect of program
Endangered Species Act of 1973 (P.L. 93–205)	FWS	Provides for the designation and protection of wildlife, fish, and plant species that are in danger of extinction.
* Executive Order 11990, Protection of Wetlands (1977)	AFA	Requires Federal agencies to minimize impacts of Federal activities on wetlands.
* Executive Order 11988, Protection of Floodplains (1977)	AFA	Requires Federal agencies to minimize impacts of Federal activities on flood plains.
Executive Order 12580, Superfund Implementation (1987)	DOI	Directs DOI to develop rules for assessing damages under CERCLA (Comprehensive Environmental Response Compensation and Liabilities Act) as a natural resource trustee.
Federal Noxious Weed Act (P.L. 93–629) (1975)	DOI, USDA DOE, DOD	Authorizes controlling the spread of noxious weeds on Federal lands.
Federal Power Act (41 Stat. 1063) (1920)	FERC	FERC will cooperate with other Federal agencies in assessing proposed power projects, such as dams. FERC must consider protection of fish and wildlife resources.
Fish and Wildlife Coordination Act (1965) (P.L. 89–72)	FWS	Requires Federal agencies to consult with FWS before issuing permits for most water-resource projects.
Food, Agriculture, Conservation, and Trade Act of 1990 (P.L. 101–624)	NRCS	Wetland Reserve Program purchases perpetual nondevelopment easements on farmed wetlands. Subsidizes restoration of croplands to wetlands.
* Food Security Act of 1985 (*Swampbuster*) (P.L. 99–198)	ASCS, FWS, FmHA	"Swampbuster" program suspends agricultural subsidies for farmers who convert wetlands to agriculture. Conservation Easements program allows FmHA to eliminate some farm debts in exchange for long-term easements that protect wetlands and other areas.
National Wildlife Refuge System Administration Act of 1966 (P.L. 89–669)	DOI	Provides the guidelines for managing National Wildlife Refuges.
Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (P.L. 101–646)	FWS, USCG, EPA, Corps, NOAA	Created a Federal program to prevent and control the spread of species that are aquatic nuisances.
Oil Pollution Act of 1990 (P.L. 101–380)	DOE, DOI, NOAA	Enhanced the response to oil spills and required natural resource damage assessments.
Tax Deductions for Conservation Easements (Section 6 of P.L. 96–541)	IRS	Allows taxpayers to take a deduction for a qualified real property interest contributed to a conservation organization for conservation purposes.
U.S. Tax Code Reform Act of 1986 (P.L. 99–514)	IRS	Eliminates incentives for clearing land. Deductible conservation expenditures must be consistent with wetlands protection. Capital gains on converted wetlands treated as income.
Water Resources Development Act of 1976, 1986, 1988, 1990, (P.L.'s 94–587, 99–662, 100–676, 101–640)	Corps	States that future mitigation plans for Federal water projects should include "in kind" mitigation for bottom-land hardwood forests.

and clearing land, are regulated as Section 404 discharges if they involve discharges of more than incidental amounts of soil or other materials into wetlands or other waters.

The Corps and the EPA share the responsibility for implementing the permitting program under Section 404 of the Clean Water Act. However, Section 404(c) of the Clean Water Act gives the EPA authority to veto the permit if discharge materials at the selected sites would adversely affect such things as municipal water supplies, shellfish beds and fishery areas, wildlife, or recreational resources. By 1991, the EPA had vetoed 11 of several hundred thousand permits since the Act was passed (Schley and Winter, 1992).

The review process for a Section 404 permit is shown in figure 39. After notice and opportunity for a public hearing, the Corps' District Engineer may issue or deny the permit. The District Engineer must comply with the EPA's Section 404(b)(1) Guidelines and must consider the public interest when evaluating a proposed permit. Four questions related to the guidelines are considered during a review of an application:

1. Is the proposed discharge the least damaging practical alternative?
2. Does the proposed discharge comply with other environmental standards or regulations?
3. Will the proposed discharge significantly degrade wetlands?
4. Have all the appropriate and practical steps been taken to minimize potential harm to the wetlands?

Wetland mitigation is often required, and if required, the permit applicant will need to develop a specific, detailed plan.

Through a public interest review, the Corps tries to balance the benefits an activity may provide against the costs it may incur. The criteria applied in this process are the relative extent of the public and private need for the proposed structure or work and the extent and permanence of the beneficial or detrimental effects on the public and private uses to which the area is suited. Some of the factors considered in the public interest review are listed in figure 39. Cumulative effects of numerous piecemeal changes are considered in addition to the individual effects of the projects.

The FWS, NOAA, and State fish and wildlife agencies, as the organizations in possession of most of the country's biological data, have important advisory roles in the Section 404 program. The FWS and NOAA (if a coastal area is involved) provide the Corps and the EPA with comments about the potential environmental effects of pending Section 404 permits. Other government agencies, industry, and the public are invited to participate through public notices of permit applications, hearings, or other information-collecting activities. However, the public interest review usually does not involve public comment unless the permit is likely to generate significant public interest or if the potential consequences of the permit are expected to be significant. All recommendations must be given full consideration by the Corps, but there is no requirement that they must be acted upon.

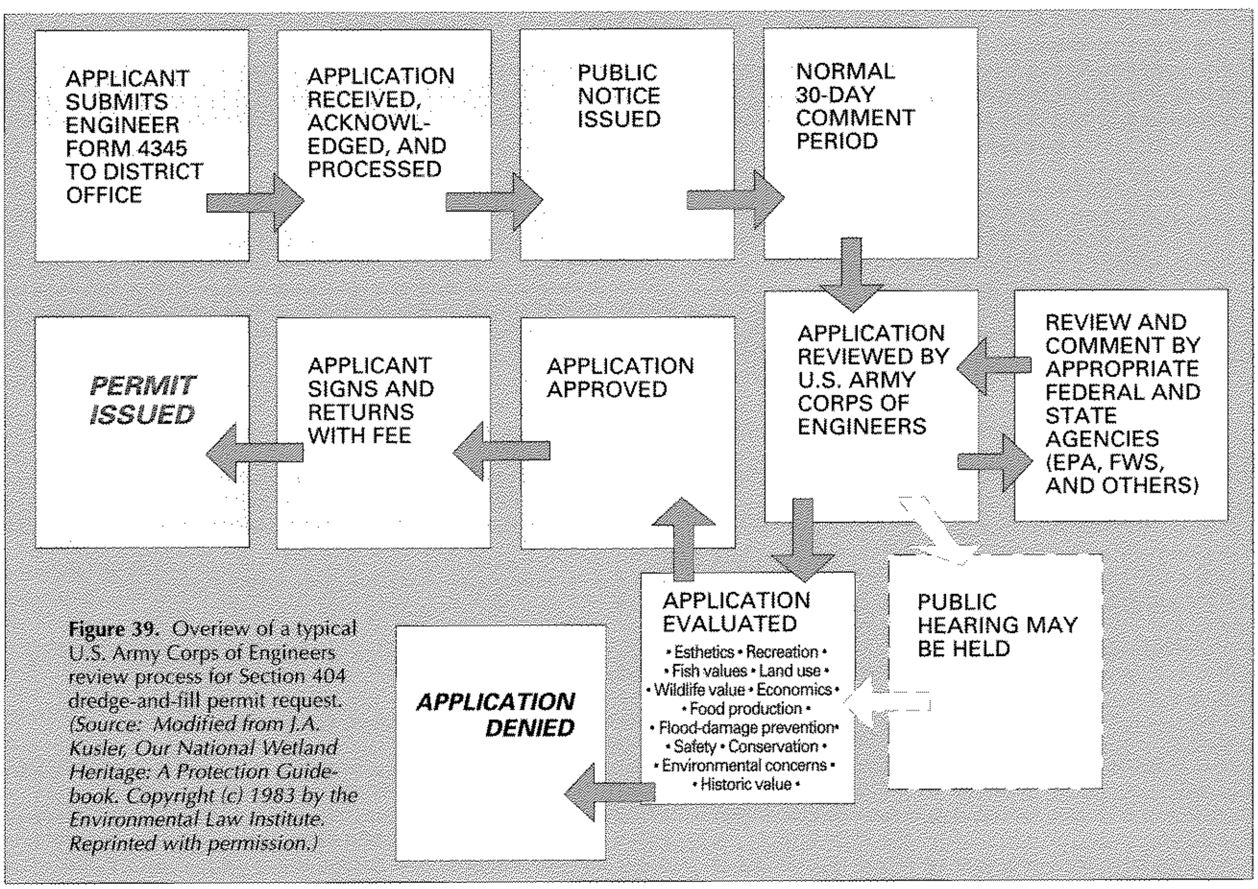

Figure 39. Overview of a typical U.S. Army Corps of Engineers review process for Section 404 dredge-and-fill permit request. *(Source: Modified from J.A. Kusler, Our National Wetland Heritage: A Protection Guidebook. Copyright (c) 1983 by the Environmental Law Institute. Reprinted with permission.)*

If the FWS or NOAA disagree with a permit approved by a District Engineer, they can request that the permit be reviewed at a higher level within the Corps. However, the Assistant Secretary of the Army has the unilateral right to refuse all requests for higher level reviews. The Assistant Secretary accepted the additional review of 16 of the 18 requested out of the total 105,000 individual permits issued between 1985 and 1992 (Schley and Winter, 1992).

Because many activities may cause the discharge of dredged and fill materials, and the potential effects of these activities differ, the Corps has issued general regulations to deal with a wide range of activities that could require a Section 404 permit. The Corps can forgo individual permit review by issuing general permits on a State, regional, or nationwide basis. General permits cover specific categories of activities that the Corps determines will have minimal effects on the aquatic environment, including wetlands. General permits are designed to allow activities with minimal effects to begin with little, if any, delay or paperwork. General permits authorize approximately 75,000 activities annually that might otherwise require a permit (U.S. Environmental Protection Agency, 1991); however, most activities in wetlands are not covered by general permits (Morris, 1991).

Not all dredge and fill activities require a Section 404 permit. Many activities that cause the discharge of dredged and fill materials are exempt from Section 404. The areas specifically exempted from Section 404 include: normal farming, forestry, and ranching activities; dike, dam, levee, and other navigation and transportation structure maintenance; construction of temporary sedimentation basins on construction sites; and construction or maintenance of farm roads, forest roads, or temporary roads for moving mining equipment (Morris, 1991). In addition, the Corps' flood-control and drainage projects and other Federal projects authorized by Congress and planned, financed, and constructed by a Federal agency also are exempt from the Section 404 permitting requirements if an adequate environmental impact statement is prepared.

Not all methods of altering wetlands are regulated by Section 404. Common methods of altering wetlands are listed in table 7. Unregulated methods include: wetland drainage, the lowering of ground-water levels in areas adjacent to wetlands, permanent flooding of existing wetlands, deposition of material that is not specifically defined as dredged and fill material by the Clean Water Act, and wetland vegetation removal (Office of Technology Assessment, 1984).

State authority over the Federal Section 404 program is a goal of the Clean Water Act. Assumption of authority from the EPA has been completed only by Michigan and New Jersey. Under this arrangement, the EPA is responsible for approving State assumptions and retains oversight of the State Section 404 program, and the Corps retains the navigable waters permit program (Mitsch and Gosselink, 1993). States cannot issue permits over EPA's objection, but EPA has the authority to waive its review for selected categories of permit applications. Few States have chosen to assume the program, in part because few Federal resources are available to assist States and assumption does not include navigable waters (World Wildlife Fund, 1992).

The Clean Water Act regulates dredge and fill activities that would adversely affect wetlands.

Table 7. Methods of altering wetlands
[Source: The Conservation Foundation, 1988, p. 15]

PHYSICAL	
Filling	adding any material to raise the bottom level of a wetland or to replace the wetland with dry land
Draining	removing the water from a wetland by ditching, tiling, pumping, and so forth
Excavating	dredging and removing soil and vegetation from a wetland
Diverting water away	preventing the flow of water into a wetland by removing water upstream, lowering lake levels, or lowering ground-water tables
Clearing	removing vegetation by burning, digging, application of herbicide, scraping, mowing, or otherwise cutting
Flooding	raising water levels, either behind dams, by pumping, or otherwise channeling water into a wetland
Diverting or withholding sediment	trapping sediment by constructing dams, channels, or other types of projects, thereby inhibiting wetland regeneration in natural deposition areas such as deltas
Shading	placing pile-supported platforms or bridges over wetlands, causing vegetation to die because of a lack of adequate sunlight
Conducting activities in adjacent areas	disrupting the interactions between wetlands and adjacent land areas, or incidentally affecting wetlands through activities at adjoining sites
CHEMICAL	
Changing nutrient levels	increasing or decreasing nutrient levels within the local water and or soil system, forcing wetland plant community changes
Introducing toxics	adding toxic compounds to a wetland either intentionally (for example, herbicide treatment to reduce vegetation) or unintentionally, adversely affecting wetland plants and animals
BIOLOGICAL	
Grazing	consumption and compaction of vegetation by domestic or wild animals
Disrupting natural populations	reducing populations of existing species, introducing exotic species, or otherwise disturbing resident organisms

"Swampbuster"

"Swampbuster" removes Federal incentives for the agricultural conversion of wetlands.

The program that seeks to remove Federal incentives for the agricultural conversion of wetlands is part of the Food Security Act of 1985 and 1990, and is known as "Swampbuster." Swampbuster renders farmers who drained or otherwise converted wetlands for the purpose of planting crops after December 23, 1985, ineligible for most Federal farm subsidies. Through Swampbuster, Congress directed the U.S. Department of Agriculture (USDA) to slow wetland conversion by agricultural activities (U.S. Fish and Wildlife Service, 1992). The government programs that Swampbuster specifically affects are listed in Section 1221 of the Food Security Act. If a farmer loses eligibility for USDA programs under Swampbuster, he or she may regain eligibility during the next year simply by not using wetlands for growing crops. Swampbuster is administered by USDA's Consolidated Farm Service Agency. The NRCS and the FWS serve as technical consultants (World Wildlife Fund, 1992).

The Swampbuster was amended by the Food, Agriculture, Conservation, and Trade Act of 1990 to create the Wetland Reserve Program. The Wetland Reserve Program provides financial incentives to farmers to restore and protect wetlands through the use of long-term easements (usually 30-year or permanent). The program provides farmers the opportunity to offer a property easement for purchase by the USDA and to recieve cost-share assistance (from 50 to 75 percent) to restore converted wetlands. Landowners make bids to participate in the program. The bids represent the payment they are willing to accept for granting an easement to the Federal Government. The Consolidated Farm Service Agency ranks the bids according to the environmental benefit per dollar. Easements require that farmers implement conservation plans approved by the NRCS and the FWS. Enrollment in the pilot program was authorized for nine States. The program's goal is to enroll 1 million acres by 1995 (U.S. Fish and Wildlife Service, 1992). Funding for this program is appropriated annually by Congress (U.S. Army Corps of Engineers, 1994). Because 74 percent of United States' wetlands are on private land, programs that provide incentives for private landowners to preserve their wetlands, such as the Wetland Reserve Program, are critical for protecting wetlands (Council of Environmental Quality, 1989).

Coastal Wetlands Protection Programs

The Coastal Zone Management Program provides States with some control over wetland resources.

The 1972 Coastal Zone Management Act and the 1982 Coastal Barriers Resources Act protect coastal wetlands. The Coastal Zone Management Act encourages States (35 States and territories are eligible, including the Great Lakes States) to establish voluntary coastal zone management plans under NOAA's Coastal Zone Management Program and provides funds for developing and implementing the plans. The NOAA also provides technical assistance to States for developing and implementing these programs. For Federal approval, the plans must demonstrate enforceable standards that provide for the conservation and environmentally sound development of coastal resources. The program provides States with some control over wetland resources by requiring that Federal activities be consistent with State coastal zone management plans, which can be more stringent than Federal standards (World Wildlife Fund, 1992, p. 87). A State also can require that design changes or mitigation requirements be added to Section 404 permits to be consistent with the State coastal zone management plan. The Coastal Zone Management Act has provided as much as 80 percent of the matching-funds grants to States to develop plans for coastal management that emphasize wetland protection (Mitsch and Gosselink, 1993). Some States pass part of the grants on to local governments. The Act's authorities are limited to wetlands within a State's coastal zone boundary, the definition of which differs among States. As of 1990, 23 States had federally approved plans.

The 1982 Coastal Barriers Resources Act denies Federal subsidies for development within undeveloped, unprotected coastal barrier areas, including wetlands, designated as part of the Coastal Barrier Resources System. Congress designates areas for inclusion in the Coastal Barriers Resource System on the basis of some of the following criteria (Watzin, 1990):

- Size
- Development status
- Composition
- Wind, wave, and tidal energies
- Associated aquatic habitat, including adjacent wetlands

In addition, States, local governments, and conservation organizations owning lands that were "otherwise protected" could have their lands added to this system until May 1992. ("Otherwise protected" lands are areas within undeveloped coastal barriers that were already under some form of protection.) Once in the Coastal Barriers Resources System, these areas are rendered ineligible for almost all Federal financial subsidies for programs that might encourage development. In particular, these lands no longer qualify for Federal flood insurance, which discourages development because coastal lands are frequently subject to flooding and damage from hurricanes and other storms. The FWS is responsible for mapping these areas and approves lands to be included in the system. The purposes of the Coastal Barrier Resources Act are to minimize the loss of human life, to reduce damage to fish and wildlife habitats and other valuable resources, and to reduce wasteful expenditure of Federal revenues (Watzin, 1990). In the future, eligible surplus government land will be included if approved by the FWS. About 95 percent of the 788,000 acres added to the system in 1990 along the Atlantic and Gulf coasts consists of coastal wetlands and near-shore waters (World Wildlife Fund, 1992).

Flood-Plain and Wetland Protection Orders

Executive Orders 11988, *Floodplain Management*, and 11990, *Protection of Wetlands*, were signed by President Carter in 1977. The purpose of these Executive Orders was to ensure protection and proper management of flood plains and wetlands by Federal agencies. The Executive Orders require Federal agencies to consider the direct and indirect adverse effects of their activities on flood plains and wetlands. This requirement extends to any Federal action within a flood plain or a wetland except for routine maintenance of existing Federal facilities and structures. The Clinton administration has proposed revising Executive Order 11990 to direct Federal agencies to consider wetland protection and restoration planning in the larger scale watershed/ecosystem context.

WETLAND DELINEATION STANDARDS

The Corps published, in 1987, the *Corps of Engineers Wetland Delineation Manual,* a technical manual that provides guidance to Federal agencies about how to use wetland field indicators to identify and delineate wetland boundaries (U.S. Army Corps of Engineers, 1987). In January of 1989, the EPA, Corps, SCS, and FWS adopted a single manual for delineating wetlands under the Section 404 and Swampbuster programs—*The Federal Manual for Identifying and Delineating Jurisdictional Wetlands* (commonly referred to as the "1989 Manual"). The "1989 Manual" establishes a national standard for identifying and delineating wetlands by specifying the technical criteria used to determine the presence of the three wetland characteristics: wetland hydrology, water-dependent vegetation, and soils that have developed under anaerobic conditions (U.S. Environmental Protection Agency, 1991).

In 1991, the President's Council on Competitiveness proposed revisions to the 1989 Manual because of some concern that nonwetland areas were regularly being classified as wetlands (Environmental Law Reporter, 1992a). The proposed 1991 Manual was characterized by many wetland scientists as politically based rather than scientifically based. In September of 1992, Congress authorized the National Academy of Science to conduct a $400,000 study of the methods used to identify and delineate wetlands (Environmental Law Reporter, 1992b). On August 25, 1993, the Clinton administration's wetland policy, proclaimed that, "Federal wetlands policy should be based upon the best science available" (White House Office of Environmental Policy, 1993) and the 1987 Corps Manual is the sole delineation manual for the Federal Government until the National Academy of Sciences completes its study (White House Office of Environmental Policy, 1993).

MITIGATION

Mitigation is the attempt to alleviate some or all of the detrimental effects arising from a given action. Wetland mitigation replaces an existing wetland or its functions by creating a new wetland, restoring a former wetland, or enhancing or preserving an existing wetland. This is done to compensate for the authorized destruction of the existing wetland. Mitigation commonly is required as a condition for receiving a permit to develop a wetland.

Wetland mitigation can be conducted directly on a case-by-case onsite basis, or through a banking system. Onsite mitigation requires that a developer create a wetland as close as possible to the site where a wetland is to be destroyed. This usually involves a one-to-one replacement.

A mitigation bank is a designated wetland that is created, restored, or enhanced to compensate for future wetland loss through development. It may be and usually is located somewhere other than near the site to be destroyed and built by someone other than the developer. The currency of a mitigation bank is the mitigation credit. "Mitigation banks require systems for valuing the compensation credits produced and for determining the type and number of credits needed as compensation for any particular project. ***Mitigation bank credit definitions are an attempt to identify those features [of wetland] which allow reasonable approximations of replacement" (U.S. Army Corps of Engineers, 1994, p. 63). Wetland evaluation methods have been developed or are being developed to address the problem of evaluating two different wetlands so that the degradation of one can be offset by the restoration, enhancement, or creation of the other and to assign either a qualitative or quantitative value to each wetland. When buying the credits, developers pay a proportionate cost toward acquiring, restoring, maintaining, enhancing, and monitoring the mitigation bank wetland. Banks cover their costs by selling credits to those who develop wetlands, or by receiving a taxpayer subsidy.

Several problems are associated with wetland mitigation. The concept of wetland compensation may actually encourage destruction of natural wetlands if people believe that wetlands can be easily replaced. A 1990 Florida Department of Environmental Regulation study examined the success of wetland creation projects and found that the success rate of created tidal wetlands was 45 percent, whereas the success rate for created freshwater wetlands was only 12 percent. (Redmond, 1992). Figure 40 shows the relative success of wetland mitigation projects overall in south Florida. The apparent factor controlling the lower success rate for freshwater wetlands was the difficulty in duplicating wetland hydrology, that is, water-table fluctuations, frequency and seasonality of flooding, and ground-water/surface-water interactions.

A study of wetland mitigation practices in eight States revealed that in most of the States, more wetland acreage was destroyed than was required to be created or restored, resulting in a net loss of acreage when mitigation was included in a wetlands permit (Kentula and others, 1992). Less than 55 percent of the permits included monitoring of the project by site visit. A limited amount of information exists about the number of acres of wetlands affected by mitigation or the effectiveness of particular mitigation techniques because of the lack of followup. Several studies in Florida reported that as many as 60 percent of the required mitigation projects were never even started (Lewis, 1992). In addition, the mitigation wetland commonly was not the same type of wetland that was destroyed, which resulted in a net loss of some wetland types. (See article "Wetland Restoration and Creation" in this volume.)

RECENT PRESIDENTIAL WETLAND PROTECTION INITIATIVES

In his 1988 Presidential address and in his 1990 budget address to Congress, President Bush echoed the recommendations of the National Wetland Policy Forum. The Forum was convened in 1987 by the Conservation Foundation at the request of EPA. The short-

"Federal wetlands policy should be based upon the best science available."

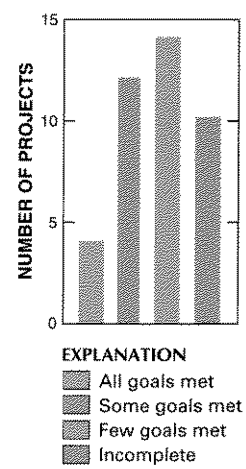

Figure 40. Status of 40 wetland mitigation projects in south Florida. The average age of the projects was less than 3 years. *(Source: Modified from Mitsch and Gosselink, 1993.)*

term recommendation of the forum was to decrease wetland losses and increase wetland restoration and creation—the concept of "no net loss"—as a national goal. This implied that when wetland loss was unavoidable, creation and restoration should replace destroyed wetlands (Mitsch and Gosselink, 1993).

On August 25, 1993, President Clinton unveiled his new policy for managing America's wetland resources. The program was developed by the Interagency Working Group on Federal Wetlands Policy, a group chaired by the White House Office on Environmental Policy with participants from the EPA, the Corps, the Office of Management and Budget, and the Departments of Agriculture, Commerce, Energy, Interior, Justice, and Transportation. The Administration's proposals mix measures that tighten restrictions on activities affecting wetlands in some cases and relax restrictions in other areas. The Clinton policy endorses the goal of "no net loss" of wetlands; however, it clearly refers to "no net loss" of wetland acreage rather than "no net loss" of wetland functions.

"No net loss" of wetlands is a national goal.

The President's wetland proposal would expand Federal authority under the Section 404 program to regulate the draining of wetlands in addition to regulating dredging and filling of wetlands. Other proposed changes to the Federal permitting program include the requirement that most Section 404 permit applications be approved or disapproved within 90 days, and the addition of an appeal process for applicants whose permits are denied. The EPA and the Corps are directed to relax regulatory restrictions that cause only minor adverse effects to wetlands such as activities affecting very small areas.

The Clinton policy calls for avoiding future wetland losses by incorporating wetland protection into State and local government watershed-management planning. This new policy also significantly expands the use of mitigation banks to compensate for federally approved wetland development or loss.

Clinton's proposals relaxed some of the current restrictions on agricultural effects on wetlands and increased funding for incentives to preserve and restore wetlands on agricultural lands. The administration policy excluded 53 million acres of "prior converted croplands" from regulation as wetlands. Also, authority over wetland programs affecting agriculture was shifted from the FWS to the NRCS and proposed increased funding for the Wetlands Reserve Program, which pays farmers to preserve and restore wetlands on their property.

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Wetland Management and Research

Wetland Research by Federal Agencies

By Richard E. Coleman[1], Edward T. LaRoe[2], and Russell F. Theriot[1]

Because wetlands were drained and filled for farming and building purposes during the last several hundred years, more than half of the original wetlands in the United States have been lost (Frayer and others, 1983). Only during the last quarter century has society begun to understand the value of wetlands and the particular benefits that they provide. (See the article "History of Wetlands in the Conterminous United States" in this volume.) This understanding has been broadened by the concerted efforts of many public and private researchers. This article addresses the research contributions of Federal agencies: which agencies are involved in wetland research, why they are involved, and the nature of their research.

In an effort to develop a strategy for preventing the further loss of wetlands, the Committee on Earth and Environmental Sciences established a Wetlands Research Subcommittee to determine the status of wetland research being conducted by Federal agencies. These efforts resulted in an unpublished report that presented a national inventory and data base of ongoing research and addressed future research needs (Wetlands Research Subcommittee, unpub. data, 1992). Data presented in the following few pages are drawn largely from these findings.

During 1992, Federal wetland research expenditures were about $63 million. A total Federal investment of more than $250 million is distributed over the lifetime of the existing projects. The amount of Federal research spending per State is depicted in figure 41.

THE REASONS FOR FEDERAL INVOLVEMENT IN WETLAND RESEARCH

Scientists from many organizations, including those in the private sector, those from colleges and universities, and those from public institutions, are engaged in wetland research. Typically, each organization has its own reasons for being involved in wetland research. Federal wetland research may be done because it is part of an agency's mission, is part of an agency's responsibilities as outlined by the Congress, or is otherwise in the national interest.

When research is mission oriented, it is part of the basic work of an agency. Mission-oriented Federal agency wetland research generally is done for one of five reasons:

1. Ownership—The agency owns and is responsible for managing wetlands. The agency is the steward of its land.
2. Public trust responsibilities—An agency may be responsible for ensuring the long-term survival of certain fish and other wildlife resources, which are

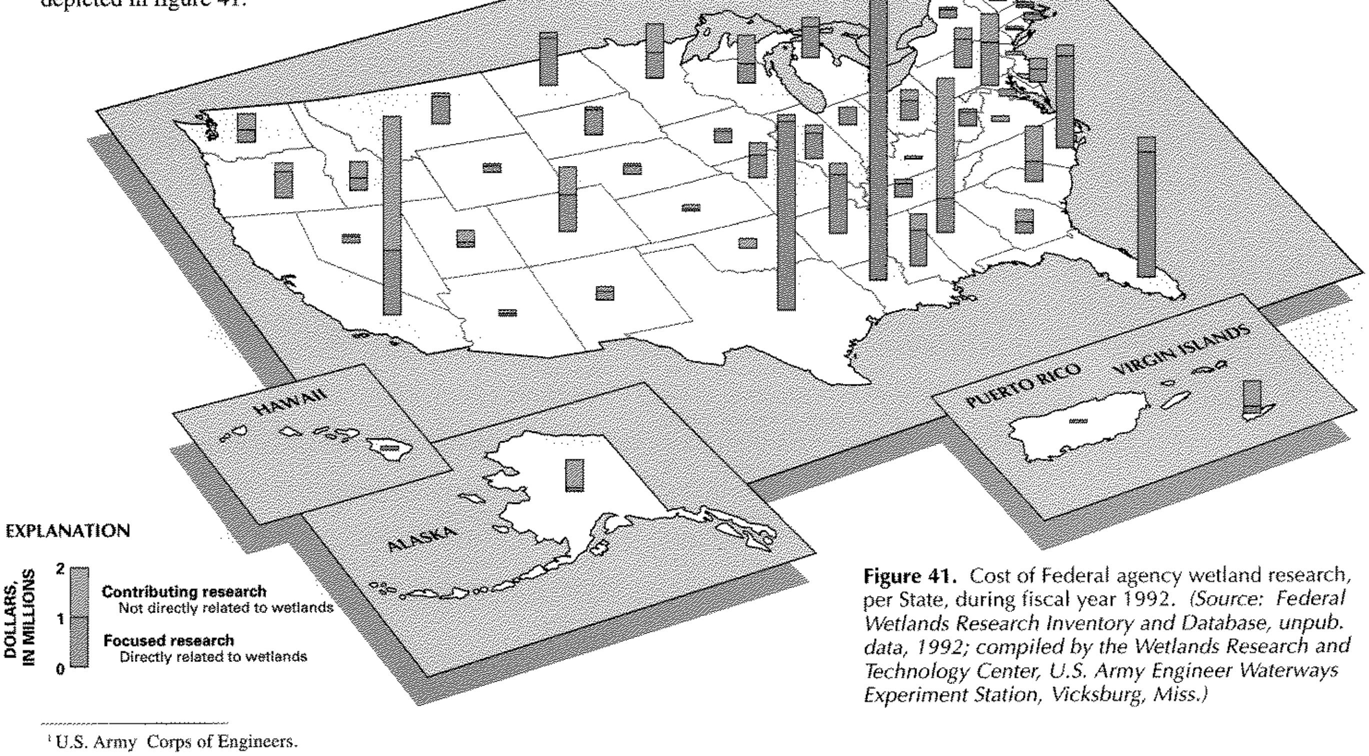


Figure 41. Cost of Federal agency wetland research, per State, during fiscal year 1992. *(Source: Federal Wetlands Research Inventory and Database, unpub. data, 1992; compiled by the Wetlands Research and Technology Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.)*

[1] U.S. Army Corps of Engineers.
[2] National Biological Service.

held in trust for the public. Wetlands form critical habitat and are part of the ecological system on which many of these species depend.

3. Regulatory responsibilities—Because wetlands provide so many benefits to society, activities that adversely affect them may be subject to regulation. Some agencies, therefore, have regulatory authority over wetlands.
4. Development activities—Federal agencies have an obligation to avoid projects or actions that may adversely affect wetlands, to minimize the negative effects of their activities on wetlands, and to mitigate unavoidable wetland losses. These requirements apply to all Federal agencies, but those regularly involved in large-scale development projects support specific wetland research activities.
5. Science—Agencies that have missions directly related to science may conduct or support research on wetlands.

The understanding of wetlands as a valued resource has been broadened by the concerted efforts of many public and private researchers.

Although many different levels of government may have mission-oriented research, Federal agency wetland research activities relate to congressionally mandated responsibilities. Most significant among these are provisions that relate to:

- Interstate commerce—Wetlands are part of the entire physical landscape, from river headwaters to the sea. They form parts of water bodies that provide shipping, transportation, and navigation. Some wetlands are used as routes for trade in interstate commerce, and wetland products are used in interstate trade. What happens to wetlands in one State can affect wetland activities, benefits, and uses in another State.
- International treaties—The benefits and uses of wetlands are the subject of international treaties, such as the Ramsar Convention of 1971 and the Migratory Bird Treaty, which are the exclusive domain of the Federal Government. International efforts that result from those treaties, such as efforts between Canada, Mexico, and the United States to restore declining wetland-dependent waterfowl populations, have an essential Federal element. (See article "Wetlands as Bird Habitat" in this volume.)

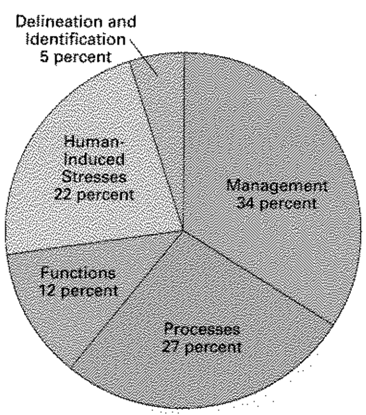
There is also an intrinsic national interest in wetland research. Where wetland questions or issues are widespread or shared by jurisdictions, or affect the national health, safety, or welfare, Congress may determine that there is a national interest that justifies Federal agency research.

TYPES OF FEDERAL WETLAND RESEARCH

The Federal Wetlands Research Inventory and Database reported in 1992 that 18 Federal agencies were conducting some wetland research (Wetlands Research Subcommittee, unpub. data, 1992). Two types of research were included in the inventory—focused and contributing. Focused research is specifically designed to investigate wetlands or some component thereof; contributing research provides some information about wetlands but is not directly related to wetlands.

Research categories also were identified by the Inventory and Database. These categories were defined by the subject of the wetland research being conducted, and were listed in five topical areas:

1. Wetland processes—Research to address factors that affect the type, location, size, and functions of wetlands.
2. Wetland functions—Research to determine the role wetlands play and the benefits they provide.
3. Human-induced stresses—Research to improve ways of detecting or quantifying the effects of



AGENCY		RESEARCH CATEGORY				
		PROCESSES	FUNCTIONS	HUMAN-INDUCED STRESSES	DELINEATION AND IDENTIFICATION	MANAGEMENT
Army Corps of Engineers	Corps	$ 1,072,000	$ 438,000	$ 154,000	$ 364,000	$ 4,818,000
Agricultural Research Service	ARS	814,000	0	65,000	0	909,000
Bureau of Mines	BOM	316,000	49,000	0	0	0
Bureau of Reclamation	BOR	25,000	25,000	0	0	150,000
Department of Energy	DOE	2,698,000	2,126,000	2,195,000	1,279,000	2,110,000
Federal Highway Administration	FHA	77,000	39,000	29,000	347,000	100,000
Minerals Management Service	MMS	500,000	0	0	0	0
National Oceanic and Atmospheric Administration	NOAA	267,000	2,144,000	523,000	100,000	165,000
National Park Service	NPS	1,046,000	0	194,000	0	531,000
National Science Foundation	NSF	269,000	0	0	0	0
Office of Surface Mining	OSM	0	0	0	0	147,000
Smithsonian Institute	SMI	847,000	100,000	32,000	88,000	1,000
Soil Conservation Service*	SCS	32,000	0	0	0	2,014,000
Tennessee Valley Authority	TVA	55,000	167,000	70,000	0	2,674,000
U.S. Environmental Protection Agency	EPA	150,000	586,000	0	0	2,320,000
U.S. Fish and Wildlife Service	FWS	2,366,000	1,027,000	7,039,000	771,000	4,916,000
U.S. Forest Service	USFS	213,000	409,000	13,000	0	412,000
U.S. Geological Survey	USGS	6,534,000	844,000	3,456,000	118,000	1,567,000

* Became the Natural Resources Conservation Service in 1994.

Figure 42. Summary of Federal agency wetland research expenditures by research category during 1992. *(Source: Federal Wetlands Research Inventory and Database, unpub. data, 1992; compiled by the Wetlands Research and Technology Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.)*

stress on wetlands, or of determining stress thresholds of wetlands.

4. Wetland delineation and identification—Research on methods and techniques to identify wetlands and delineate wetland boundaries.
5. Management—Research to develop tools and technologies to maintain, restore, and construct wetlands.

Figure 42 depicts the expenditures on Federal research in each of these categories in 1992. Individual research studies may span several of these categories; however, these categories represent a convenient way to describe existing research activities.

In addition to distinguishing the type of research, it also is useful to distinguish the type of wetland being studied. Because ecological processes and functions differ with the type of wetland, research needs and techniques also differ. Disappearing coastal and bottom-land hardwood wetlands are among the major areas of research. Figure 43 shows Federal expenditures for research on different types of wetlands. (See article "Wetland Definitions and Classification in the Conterminous United States" for an explanation of wetland types.)

AGENCY ROLES AND RESPONSIBILITIES

Federal wetland research is conducted throughout the Nation. Twelve agencies listed in the Wetland Research Subcommittee's report and discussed below have wetland research expenditures of $1 million or more. Although not discussed below, other agencies with less funding that also contribute to wetland research are the Department of the Interior's Bureau of Mines, Bureau of Reclamation, Minerals Management Service, and Office of Surface Mining; the Federal Highway Administration's Department of Transportation; and the National Science Foundation.

Department of the Interior

Wetland research activities in the Department of the Interior relate to its responsibilities as the primary steward of America's natural resources. The Department of the Interior performs basic scientific research on wetland processes and functions and applied focused research on human-induced stresses, delineation and identification, and management of wetlands. The Department assumes ownership and management responsibilities for wetlands through the U.S. Fish and Wildlife Service (FWS) and the National Park Service, and scientific research responsibilities through the activities of the U.S. Geological Survey (USGS) and the National Biological Service (NBS). Research funding for the Department was greater than $30.5 million in 1992 (figs. 42–43).

U.S. Fish and Wildlife Service: The FWS has stewardship responsibilities for fish and other wildlife (such as migratory birds, anadromous fish, and endangered species), their habitats, and for wildlife refuges. As a major Federal landowner, the FWS protects and manages wetlands and associated habitats on more than 90 million acres of national wildlife refuges and provides advice about and technical support for regulatory activities and trust species to other Federal, State, and private landowners. The FWS, through the National Wetlands Inventory program, provides detailed wetland maps for the Nation, and also reports to Congress every 10 years the status and trends of the Nation's wetlands. (See article "Wetland Mapping and Inventory" in this volume.) Research focuses on improved methods and tools for identifying and delineating different wetland types.

U.S. Geological Survey: The USGS provides geologic, hydrologic, and topographic information to assist Federal, State, and local governments, the private sector, and individual citizens in making management decisions about the use of land and water

What happens to wetlands in one State can affect wetland activities, benefits, and uses in another State.

AGENCY		WETLAND TYPES*				
		MARINE	ESTUARINE	RIVERINE	PALUSTRINE	LACUSTRINE
Army Corps of Engineers	Corps	$ 0	$ 1,750,000	$ 1,529,000	$ 2,036,000	$ 824,000
Agricultural Research Service	ARS	0	20,000	1,053,000	650,000	65,000
Bureau of Mines	BOM	0	0	0	0	0
Bureau of Reclamation	BOR	0	0	50,000	50,000	100,000
Department of Energy	DOE	153,000	418,000	1,855,000	2,640,000	406,000
Federal Highway Administration	FHA	5,000	5,000	2,000	193,000	0
Minerals Management Service	MMS	250,000	250,000	0	0	0
National Oceanic and Atmospheric Administration	NOAA	193,000	2,925,000	66,000	35,000	0
National Park Service	NPS	7,000	818,000	428,000	480,000	58,000
National Science Foundation	NSF	0	170,000	13,000	86,000	0
Office of Surface Mining	OSM	0	0	0	64,000	0
Smithsonian Institute	SMI	420,000	355,000	267,000	26,000	0
Soil Conservation Service	SCS	184,000	806,000	323,000	352,000	268,000
Tennessee Valley Authority	TVA	0	0	84,000	531,000	2,084,000
U.S. Environmental Protection Agency	EPA	150,000	225,000	736,000	1,421,000	270,000
U.S. Fish and Wildlife Service	FWS	428,000	2,949,000	5,202,000	4,033,000	3,564,000
U.S. Forest Service	USFS	0	0	102,000	945,000	0
U.S. Geological Survey	USGS	1,482,000	3,587,000	2,606,000	2,880,000	1,963,000

* Descrepancies in total expenditures occur because some agencies did not include constructed wetlands when reporting these figures.

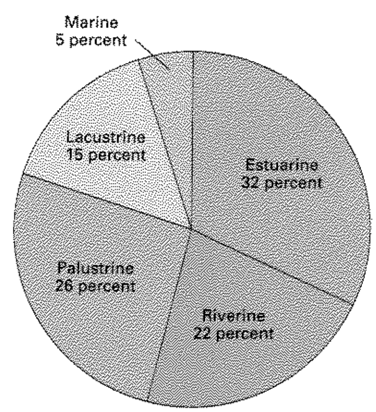


Figure 43. Summary of Federal agency wetland research expenditures by wetland type during 1992. *(Sources: Federal Wetlands Research Inventory and Database, unpub. data, 1992; compiled by the Wetlands Research and Technology Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.)*

Core sample being collected by the U.S. Geological Survey at a fen in Minn., tells the sediment history of this particular wetland. *(Photograph by Nancy Rybicki, U.S. Geological Survey.)*

The National Biological Service collects turtlegrass near Chandeleur Islands, La., to study the effects of water quality on the plant. *(Photograph courtesy of The National Biological Service.)*

The National Biological Service collects bulltongue in a marsh near Lake Salvador, La., for use in greenhouse experiments in salinity and flooding tolerance. *(Photograph courtesy of The National Biological Service.)*

resources. The USGS's wetland research activities are an important part of the agency's activities. Research focuses on the geology, chemistry, hydrology, and biology of wetlands and their interactions. Studies are conducted in selected wetlands to determine the processes responsible for the formation and evolution of wetlands and to increase understanding of wetland functions. Some specific topics that hydrologic studies address are ground-water/surface-water interactions; the role of wetlands in water-quality improvement; the relation between flood-plain wetlands, riverine and estuarine hydrology, and water quality; and the relation of light and water chemistry to aquatic plant distribution in tidal waters.

National Park Service: Wetland research by the National Park Service is primarily issue driven; it is management-oriented and focuses on protecting resources, mitigating the effects of human actions on wetlands, and restoring natural wetland functions where they have been disturbed by past or ongoing human activities.

National Biological Service: The NBS was established in October 1993 and, therefore, was not included in the report by the Wetland Research Subcommittee and not included in the graphs in figures 42–43. However, it is a large player in research being done on wetlands and, therefore, is included in this discussion. The NBS inventories and monitors wetlands and conducts biological research on many aspects of wetlands; in fact, most activities of the NBS are wetland related. It provides biological information and research support to management agencies within the Federal Government.

Department of Energy

The Department of Energy's role in and responsibilities toward wetland research are related to its compliance with environmental regulations. The Department does this by assessing the environmental effects of its activities on lands, including wetlands, under its jurisdiction, and by operating and developing facilities in ways that maintain and enhance environmental quality while providing efficient energy production, transmission, and use. Research focuses on supporting these activities. Research funding was about $10.3 million in 1992 (figs. 42–43).

Department of Defense

Wetland research activities of the Department of Defense result primarily from legislation pertaining to the mission of the U.S. Army Corps of Engineers (Corps). The Army, through the Corps, is assigned responsibility for much of the Nation's water-resource development activities, including efforts to protect, conserve, restore, and establish new wetlands. In performing its development mission, such as keeping waterways open by dredging or building levees to protect cities from flooding, the Corps directly affects wetlands and must consider the effects of its activities. The Corps has established a formal Wetlands Research Program to support its wetland-related responsibilities. This program is designed to include both basic and applied research that emphasize the Corps strengths in engineering design and construction, stewardship, and management. Research funding for the Corps in 1992 was about $6.5 million (figs. 42–43).

Department of Agriculture

The Department of Agriculture performs wetland research through several of its agencies; the Natural Resources Conservation Service (formerly known as the Soil Conservation Service), the Agricultural Research Service, and the U.S. Forest Service. Research funding for the Department of Agriculture was about $4.5 million in 1992 (figs. 42–43).

Natural Resources Conservation Service: The Natural Resources Conservation Service assists other Federal, State, and local governments in resource conservation activities that include wetland protection. Their authority covers mainly lands with high potential for conversion to agricultural uses.

The Natural Resources Conservation Service's plant materials centers develop new varieties of plants and the technology for using plants to solve soil and water-conservation problems. They also provide for the commercial production of these plants. Some of the centers conduct investigations on how to reestablish marsh vegetation along eroding tidal shores in the mid-Atlantic States and the Gulf Coast States from Alabama to Mexico. Projects are underway at other centers to develop new varieties of plants and encourage plant reproduction, to develop techniques for establishing and maintaining restored and created freshwater wetlands, and to design and construct wetlands that act as biological filters of agricultural runoff.

Economic Research Service: Although the Economic Research Service is not one of the agencies listed in the Wetland Research Subcommittee report, its research is integral to oversight of the Wetland Reserve Program by the Natural Resources Conservation Service (see the article "Wetland Protection Legislation" in this volume), and is, therefore, mentioned in this discussion. The Economic Research Service conducts cost and benefit comparison studies to determine effective economic incentives associated with wetland conservation or destruction. Because the Wetland Reserve Program is voluntary, research focuses on identifying costs that limit farmers' participation.

Agricultural Research Service: The Agricultural Research Service's mission includes development of technology needed to ensure maintenance of environmental quality and natural resources. Their research supports implementation of Federal agricultural legislation and development of new agricultural practices that produce less off-site contamination. Many programs indirectly contribute to national wetland goals by improving management of basins that drain into wetlands.

U.S. Forest Service: The U.S. Forest Service conducts research to support improved management of Federal, State, and private forests; the research comprises efforts to describe ecosystem dynamics and to develop improved technology for restoring and rehabilitating forested wetlands. Research is conducted on the role of flowing water in sustaining chemical, physical, and biological processes integral to the functioning of wetland and riparian ecosystems. The Forest Service also conducts studies of technological improvements used for reforesting wetland and riparian sites, which involves understanding how tree species adapt to flooding. Other areas of study include establishing understory vegetation, restoring wetland hydrology, and rehabilitating fish and other wildlife habitat.

The U.S. Army Corps of Engineers collects water-level data at a bottom-land hardwood wetland located along the Cache River, Ark. *(Photograph courtesy of the U.S. Army Corps of Engineers.)*

The U.S. Army Corps of Engineers dewatered this freshwater wetland at a restoration site at Kenilworth Marsh in Maryland to facilitate planting. Dewatering was achieved by building temporary dikes made from water-filled tubes designed by the Corps for this purpose. *(Photograph courtesy of the U.S. Army Corps of Engineers.)*

Department of Commerce

The Department of Commerce conducts its research through the National Oceanic and Atmospheric Administration. In 1992, funding for research by the Department was about $3 million (figs. 42–43).

National Oceanic and Atmospheric Administration: The National Oceanic and Atmospheric

National Marine Fisheries Service scientists study the effects of oyster-shell reefs on sedimentation and use by marine organisms in this created wetland at Swansboro Marsh, N.C. *(Photograph by David L. Meyer, National Marine Fisheries Service.)*

The information derived from broad-scope, individual agency research may complement that of other agencies.

Administration's (NOAA) mission is to manage our ocean and coastal resources, describe and predict changes in the Earth's oceans and atmosphere, and promote its global stewardship through scientific research and service. Three of NOAA's five organizations are directly involved in wetland research: the National Marine Fisheries Service, the National Ocean Service, and the Office of Oceanic and Atmospheric Research. NOAA also has a relevant agency-wide program, the Coastal Ocean Program, which supports management of the coastal ocean environment.

The Coastal Ocean Program is intended to provide scientific products that support coastal ocean management through improved understanding and prediction of environmental quality, fishery resources, and coastal hazards. One of the Coastal Ocean Program's component programs seeks to understand and quantify the relation between estuarine habitat and coastal ocean productivity. Initial research has been focused on locating and determining rates of loss of seagrasses, emergent marshes, and adjacent uplands using satellite and aerial photography. Research is being conducted on the functional attributes of these habitats and their capability of being restored.

National Marine Fisheries Service: This organization is the Federal steward of the Nation's living marine resources, from 200 miles offshore (the seaward extent of the Nation's assessment of mineral and energy sources) to the freshwater tributaries used by anadromous species for spawning. National Marine Fisheries Service's scientists conduct basic and applied research to advance understanding of wetland habitat functioning in response to natural and human-induced environmental changes, to develop improved techniques for habitat restoration and assessment, and to support the habitat permit review process. The National Marine Fisheries Service's Restoration Center develops and implements habitat restoration plans that seek to restore, replace, or acquire the equivalent of the resources determined to have been injured by releases of oil or hazardous substances to the environment.

National Ocean Service: This organization administers programs that provide support for managing marine environments. It manages a national network of marine sanctuaries and estuarine research reserves. The estuarine research reserves, throughout the National Estuarine Research Reserves System, are established, managed, and maintained with the help of State authorities to assure their long-term protection. Research activities are used to facilitate management of wetlands. Priorities change biennially and have included nonpoint-source pollution (1993–94) and habitat restoration (1994–95).

Office of Oceanic and Atmospheric Research: This organization is responsible for conducting research that improves understanding and prediction of oceanic and atmospheric conditions. This includes investigating processes that regulate wetland ecosystem structure and production, the responses of these systems to natural and human-induced conditions, and the effects of global climate and other atmospheric conditions on marine resources and ecosystems.

National Marine Fisheries Service scientists, using a drop sampler, collect aquatic organisms in a salt marsh on Galveston Island, Tex. This is often done to assess damages following an oil spill. *(Photograph by Lawrence P. Rozas, National Marine Fisheries Service.)*

U.S. Environmental Protection Agency

Research needs within the U.S. Environmental Protection Agency (EPA) are extensive. The Wetlands Research Program of the EPA is an applied research program that primarily provides technical support to improve the Agency's ability to carry out its regulatory responsibilities. Three components of the Wetlands Research Program are the Wetland Function Project, the Characterization and Restoration Project, and the Landscape Function Project. Detailed studies of individual wetlands conducted to understand better the processes within wetlands that contribute to wetland functions and wetland responses to environmental stressors are carried out through the Wetland Function Project. Studies of the characteristics of groups of wetlands that compare the functions of natural, restored, and created wetlands within similar geographic settings are carried out through the Characterization and Restoration Project. Research is conducted on the interactions of wetlands with other ecosystems and on the cumulative effects of human activities on wetland functions through the Landscape Function Project. In 1992, EPA's funding for wetland research was about $3 million (figs. 42–43).

Tennessee Valley Authority

The Tennessee Valley Authority (TVA) is a resource management agency created by the Tennessee Valley Authority Act of 1933. Its research focuses on both natural and constructed wetlands. Natural-wetlands research is directed toward protecting and enhancing aquatic bed, emergent, and riparian forested wetlands and the wildlife populations dependent on them. Constructed-wetlands research is directed toward designing and operating constructed wetlands to solve specific waste-management or environmental problems and examining the basic mechanics and physiology of these systems. Wetland research is conducted in the field, in laboratories, and at a unique 32-celled physical model at a constructed-wetland research facility in Muscle Shoals, Ala. In 1992, funding for research was about $3 million (figs. 42–43).

Smithsonian Institution

Smithsonian research on wetlands is focused on the biota, hydrology, and functions of wetlands. Aerial photographs, remote sensing, and Geographic Information Systems are used to extend research results from specific sites to larger regions and to relate wetlands to their drainage basins. Research support comes directly from Congress, from Smithsonian trust funds, and from extramural grants and contracts. Funding for research in 1992 was about $1 million (figs. 42–43).

COORDINATION OF RESEARCH AMONG FEDERAL AGENCIES

Federal agencies conduct wetland research to execute their congressionally mandated missions. Generally these research efforts fall within well-defined limits. By necessity, some agencies conduct research with a broad range of activities. The information derived from broad-scope, individual agency research may complement that of other agencies.

Federal agencies have special obligations, as stewards of public monies, to get the most out of research dollars. Effective coordination is essential to assure that agencies efficiently budget and use research funds, to ensure that research is not duplicated by two or more agencies (and money wasted), and to ensure that the "best science" is achieved. Federal agencies involved in wetland research use formal and informal coordination mechanisms to achieve these goals.

Informal coordination takes many forms. It includes scientists from each agency communicating directly with scientists in other agencies about matters of common interest. It also includes many adhoc committees and working groups organized to accomplish general coordination as well as specific research objectives. Among the adhoc committees is the Federal Interagency Coordination Committee on Wetlands

Local teachers work in cooperation with U.S. Environmental Protection Agency scientists to measure elevations and create site maps on this restored wetland in Portland, Oreg. *(Photograph courtesy of the U.S. Environmental Protection Agency.)*

Research and Development, a voluntary group that meets annually in Washington, D.C., to present the status of agency research programs and discuss areas of potential interaction. This Committee developed the first National Summary of Ongoing Wetlands Research by Federal Agencies (U.S. Army Engineer Waterways Experiment Station, 1992). All Federal agencies that perform wetland research are invited to these meetings. Another voluntary adhoc committee, the Forested Wetlands Research and Development Interagency Coordination Committee, formed working groups and developed a multiyear interagency research proposal for work in forested wetlands in Southern States. The Corps, the NBS, and the FWS provide funds for this research; and the EPA, Agricultural Research Service, and Natural Resources Conservation Service actually do the research.

Federal agencies have special obligations, as stewards of public monies, to get the most out of research dollars.

Federal agencies also use informal scientific reviews of individual projects and entire programs for coordination. The purpose of these reviews is to expose a project or program to external review and comment, as well as to provide a forum for exchanging views and ideas about each participating agency's project or program. The wetland research programs operated by the Corps, FWS, and EPA, and projects of the NBS's National Wetland Research Center and Cooperative Research Units Center regularly receive external peer review. Several Federal agencies regularly hold interagency planning meetings to discuss new wetland research goals and projects, solicit comments, and explore areas for potential partnerships and cooperation.

Agencies with responsibilities for regulating and managing Federal lands, which include wetlands, conduct workshops, seminars, and other informal meetings to facilitate effective interaction and coordination of their research. Professional societies, scientific literature, agency publications, newsletters, bulletins, and topical conferences also offer mechanisms for coordination and information exchange.

More formal coordination is achieved through exchange agreements, in which scientists may be exchanged from one agency to another for specific periods to provide needed expertise. As an example, the Wetlands Classification System developed by the FWS was prepared with full-time assistance of scientists from the Corps and the Soil Conservation Service, and the authors of the report defining the system (Cowardin and others, 1979) included representatives from the FWS, the USGS, and NOAA. Written agreements such as Memorandums of Agreement or Memorandums of Understanding also are used to facilitate cooperation between agencies that share mutual objectives. Reimbursable and shared funding may be used to leverage available research dollars and take advantage of specific expertise available in some agencies and lacking in others.

Formal coordination may be required by specific legislative or administrative decisions, such as the Clinton administration's decisions relating to implementation of the Breaux Bill, which requires agencies to coordinate in assessing damages and implementing corrective mechanisms in south Louisiana's coastal wetlands.

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Wetland Management and Research
Wetland Mapping and Inventory

By Bill O. Wilen[1], Virginia Carter[2], and J. Ronald Jones[2]

Wetland maps are a prerequisite for wetland inventory and for wetland development planning, management, protection, and restoration. Maps provide information on wetland type, location, and size. Detailed wetland maps are necessary for analysis of the effect of projects at specific sites and for providing baseline spatial data for the assessment of the effects of national policies and activities. Wetland maps are used by local, State, and Federal agencies, as well as by private industry and organizations. They are used for many purposes, including the development of comprehensive resource management plans, environmental impact assessments, natural resource inventories, habitat surveys, and the analysis of trends in wetland status.

Several Federal agencies map wetlands in support of their Congressional mandate. These include the U.S. Department of the Interior, U.S. Fish and Wildlife Service (FWS); the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS); and the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA). The FWS has the primary responsibility for mapping and inventory of all the wetlands of the United States. The wetland maps produced by other agencies serve different purposes and generally involve cooperation with the FWS.

THE U.S. FISH AND WILDLIFE SERVICE'S MAPPING AND INVENTORY ACTIVITIES

The FWS National Wetlands Inventory is responsible for the mapping and inventory of wetlands throughout the United States. The Emergency Wetlands Resources Act of 1986 and amendments to it in 1988 and 1992 define the responsibilities of the National Wetlands Inventory. (See the article "Wetland Protection Legislation" in this volume for more information on this and other wetland legislation.)

History and Status of the National Wetlands Inventory

In 1906, and again in 1922, the U.S. Department of Agriculture inventoried the wetlands of the United States to identify those that could be drained and converted to other uses (Wilen and Tiner, 1993). In 1954, the first nationwide wetland survey by the FWS covered about 40 percent of the conterminous United States and focused on important waterfowl wetlands. This survey was not comprehensive by today's standards, but it stimulated public interest in the conservation of waterfowl wetlands (Shaw and Fredine, 1956). (See the article "Wetlands as Bird Habitat" in this volume.)

After the earlier inventories, and in response to passage of the Emergency Wetlands Resources Act and its amendments, the FWS established the National Wetlands Inventory. The program is designed to (1) produce detailed maps on the characteristics and extent of the Nation's wetlands, (2) construct a national wetlands data base, (3) disseminate wetland maps and digital data, (4) report results of State wetland inventories, (5) report to Congress every 10 years on the status and trends of the Nation's wetlands, and (6) assemble and distribute related maps, digital data, and reports.

The National Wetlands Inventory has produced more than 50,800 maps covering 88 percent of the conterminous United States, 30 percent of Alaska, and all of Hawaii and the U.S. Territories (fig. 44) Priorities for mapping have been based on the needs of the FWS, other Federal agencies, and State agen-

Wetland maps are a prerequisite for wetland inventory, planning, management, protection, and restoration.

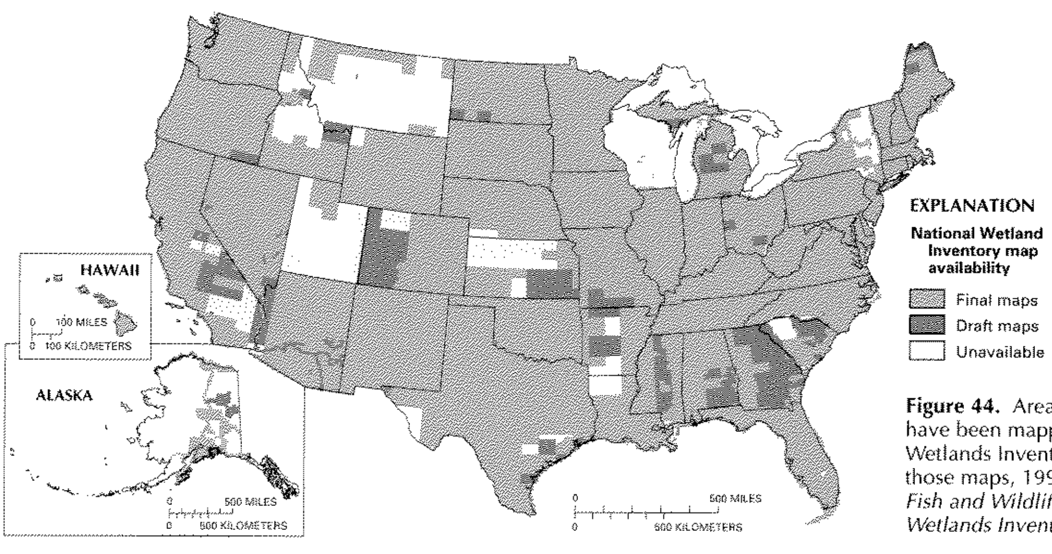


Figure 44. Areas of the United States that have been mapped by the National Wetlands Inventory program and status of those maps, 1996. *(Source: Data from U.S. Fish and Wildlife Service, National Wetlands Inventory files.)*

[1] U.S. Fish and Wildlife Service.
[2] U.S. Geological Survey.

To date, almost 18,800 maps, representing 29 percent of the United States, have been digitized.

cies. To date, mapping has been concentrated on the coastal zone (including the Great Lakes), prairie wetlands, playa lakes, flood plains of major rivers, and areas that reflect goals of the North American Waterfowl Management Plan (U.S. Fish and Wildlife Service, 1976). As a practical matter, priorities have been based on the availability of funding and the availability of high-quality aerial photographs. The National Wetlands Inventory produced maps at a rate of about 5 percent of the conterminous United States and about 2 percent of Alaska annually through 1995—about 3,200 1:24,000-scale maps in the conterminous United States and about 60 1:63,360-scale maps in Alaska.

The National Wetlands Inventory has published a series of documents on the trends in wetland losses and gains. The first of these reports was "Status and Trends of Wetlands and Deepwater Habitats in the Conterminous United States, 1950's to 1970's" (Frayer and others, 1983). In the Emergency Wetlands Resources Act of 1986 and subsequent amendments, Congress directed the National Wetlands Inventory to (1) update and improve the information contained in this report by 1990 and at 10-year intervals thereafter and (2) estimate the number of acres of wetland habitat in each State in the 1780's and the 1980's and calculate the percentage of loss in each State. In response to this directive, the National Wetlands Inventory published a 1990 report to Congress titled "Wetlands—Losses in the United States, 1780's to 1980's" (Dahl, 1990).

The National Wetlands Inventory also is preparing a geographically referenced digital data base for wetlands so that wetland information can be placed in geographic information systems (GIS) for use with computers. These digital maps and information are easily transmitted over the Internet. To date, almost 18,800 maps, representing 29 percent of the United States, have been digitized (fig. 45). Statewide data bases have been digitized for Delaware, Hawaii, Indiana, Maryland, Illinois, New Jersey, Washington, Iowa, Minnesota, and West Virginia. Digitization is in progress for Florida, North Carolina, South Carolina, South Dakota, and Virginia. Wetland digital data are available for parts of 35 other States.

In addition to wetland maps and status and trend reports, the National Wetlands Inventory produces special items related to the identification, mapping, and inventory of wetlands. The "National List of Plant Species that Occur in Wetlands" (Reed, 1988) is an important tool for identifying wetlands on the basis of their vegetation. A computerized data base for wetland plants, developed by the National Wetlands Inventory, also lists plants found in wetlands and ranks their affinity to the wetland environment. This information is important for determining whether an area is really a wetland. Additionally, the National Wetlands Inventory has contributed to a list of hydric soils (soils found in wetlands) (U.S. Soil Conservation Service, 1991). Many published State wetland reports, including "Wetlands of Maryland" (Tiner and Burke, 1995), "Wetlands of Connecticut" (Metzler and Tiner, 1992), and "Status of Alaska Wetlands" (Hall, Frayer, and Wilen, 1994), contain wetland inventory results and other important information. Finally, in cooperation with the U.S. Geological Survey (USGS), the National Wetlands Inventory has published a map (scale of 1 inch equals 50 miles) showing the locations of major wetland complexes in the conterminous United States, Hawaii, and Puerto Rico (Dahl, 1991) and a map (scale of 1 inch equals 40 miles) of Alaska's wetland resources (Hall, 1991).

OTHER FEDERAL AGENCIES' MAPPING AND INVENTORY ACTIVITIES

Natural Resources Conservation Service.—The NRCS (formerly the Soil Conservation Service) conducts its wetland inventory under the auspices of the wetland conservation provision (nicknamed "Swampbuster") of the Food Security Act of 1985. This Act provides for the reduction of a farmer's program benefits if wetlands are converted to agricultural production. In order to implement this act, the mapping of the NRCS is focused on freshwater wetlands that have a high potential for agricultural conversion, such as those adjacent to or lying within the boundaries of existing agricultural fields.

The NRCS does not produce a standard map product. Many delineations are made on 1:660-scale

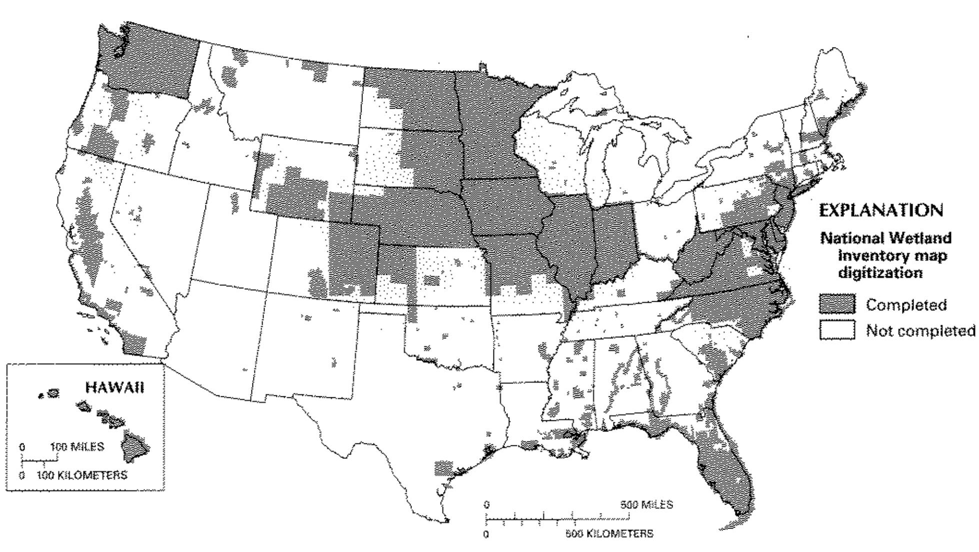
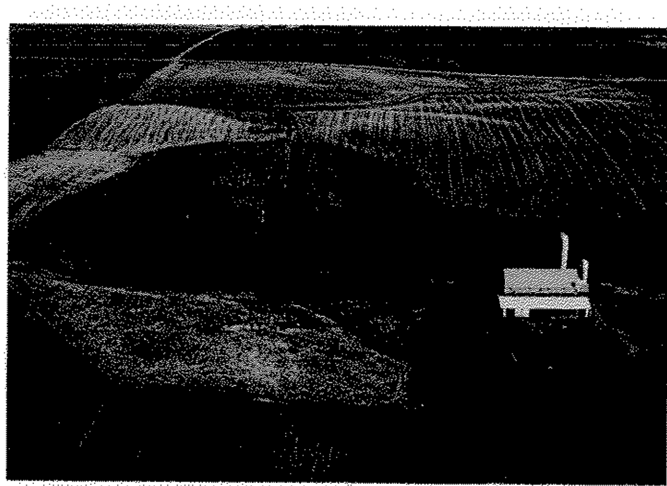
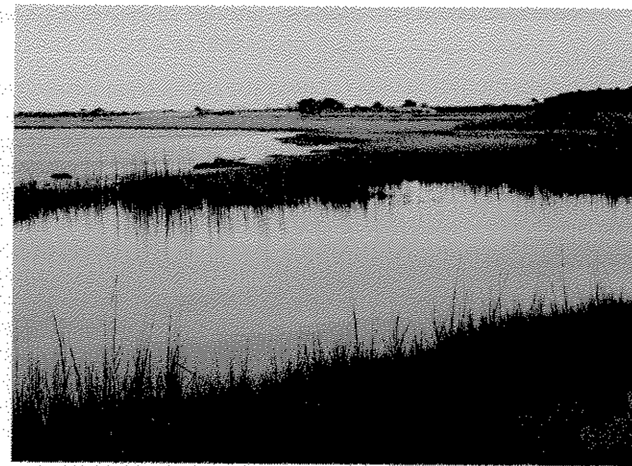


Figure 45. Areas of the conterminous United States and Hawaii where wetland data have been digitized by the National Wetlands Inventory program, 1996. *(Source: Data from U.S. Fish and Wildlife Service, National Wetlands Inventory files.)*



The "Swampbuster" discourages the conversion of wetlands to cropland. This wetland, which was converted to cropland at one time, has been restored. *(Photograph courtesy of the U.S. Fish and Wildlife Service.)*



The National Oceanic and Atmospheric Administration delineates coastal wetland and upland habitats, such as this coastal wetland at Chincoteague National Wildlife Refuge on Assateague Island, Va. *(Photograph by Judy D. Fretwell, U.S. Geological Survey.)*

black-and-white aerial photographs; others are made on soil-survey base maps at scales that range from 1:10,000 to 1:64,000 (Teels, 1990). Information sources for this program include recent and historical aerial photographs, such as those regularly acquired by the U.S. Department of Agriculture, National Wetlands Inventory maps from the FWS, U.S. Department of Agriculture crop history records, and field verifications.

National Oceanic and Atmospheric Administration.—The NOAA has developed the Coastal Wetland Habitat Change Program in order to delineate coastal wetland habitats and adjacent uplands and plains to monitor changes in these habitats on a cycle of 1 to 5 years. The basis for monitoring will be a data base describing the areal extent and distribution of coastal wetlands in the conterminous United States. The program will help to determine the linkages between estuarine and marine wetlands, as well as the distribution, abundance, and health of living marine resources.

U.S. Geological Survey.—The USGS compiles, produces, and disseminates topographic, hydrologic, and geologic maps and digital data related to wetlands. The standard USGS 1:24,000-scale topographic map commonly is used as a base for wetland mapping by other Federal, State, and local agencies. However, because USGS maps depict wetlands as unbounded symbols (fig. 46), the maps cannot be used to establish exact boundaries for wetlands. Intermediate-scale (1:100,000) and large-scale maps (scales of 1:24,000 or greater) are used for project planning. Large-scale maps known as orthophoto quadrangles, which are made by manipulation of aerial photographs to achieve a positionally accurate photographic base map, are used as a base for State wetland mapping.

COORDINATION OF FEDERAL WETLAND MAPPING EFFORTS

Differing needs of various Federal agencies can require different types of maps or different map scales. However, many needs can be satisfied by common products, and efforts are being made to standardize maps and map products whenever possible or practical. Federal digital wetland mapping is coordinated by the Wetlands Subcommittee of the Federal Geographic Data Coordination group in an effort to meet requirements established by the Office of Management and Budget. The Office of Management and Budget requires agencies to develop a national digital spatial information resource in collaboration with State and local governments and the private sector. This requirement is for the purposes of (1) promoting the development, maintenance, and management of a national digital wetland data base; (2) encouraging the development and implementation of standards, exchange formats, specifications, procedures, and guidelines; (3) promoting interaction among other Federal, State, and local government agencies that have interests in the generation, collection, use, and transfer of wetland spatial data; (4) maintaining and disseminating information on the type and availability of wetland spatial data; and (5) promoting the concept of effective wetland management.

Efforts are made to standardize maps and map products whenever possible or practical.

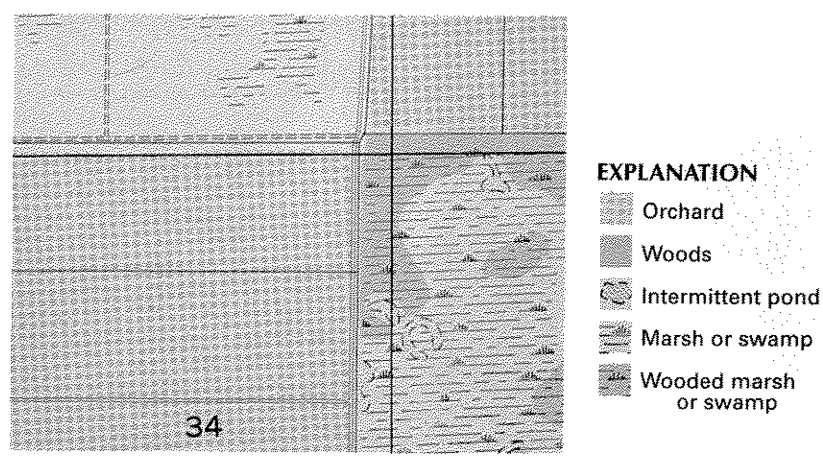


Figure 46. Unbounded symbols on a U.S. Geological Survey topographic map show the general location of wetlands.

PRODUCING NATIONAL WETLANDS INVENTORY MAPS

The National Wetlands Inventory uses the best and most appropriate aerial photographs available for mapping wetlands.

Most natural-resource inventories make use of aerial photographs or satellite images combined with field verification. The National Wetlands Inventory uses the best and most appropriate aerial photographs available for mapping wetlands. The principal data source in the early 1980's was the 1:80,000-scale, high-altitude, black-and-white aerial photography acquired by the USGS for topographic mapping and production of orthophoto quadrangles. After the USGS began its National High-Altitude Photography Program, 1:58,000-scale color-infrared photographs for the entire country became available; the National Wetlands Inventory uses these photographs extensively. In 1987, the USGS replaced the National High-Altitude Photography Program with the National Aerial Photography Program, which produces 1:40,000-scale color-infrared photographs; the National Wetlands Inventory uses these photographs as well. In some cases, the National Wetlands Inventory uses supplementary photography, such as some 1:60,000-scale color-infrared photographs of the prairie pothole region of the northern Great Plains, which were acquired from the National Aeronautics and Space Administration.

Stereoscopic color-infrared photographs are best for identifying and delineating wetlands. Color, texture, and pattern are important features of wetland vegetation and background soils. A combination of vegetation factors produce a specific response or signature on the photograph (Wilen and Pywell, 1992). These vegetation factors include leaf size, shape, structure, and arrangement; branching pattern; height; growth habit; and color. Determining the boundary of a wetland is the most difficult part of mapping. Normally, transitions are found at the boundary from upland vegetation to wetland vegetation, from nonhydric to hydric (wetland) soils, and from land that is not flooded to areas that are subject to flooding or saturation. On color-infrared photographs, water generally shows as a distinctive black and blue-black color because of its lack of reflectance. Wetlands that have canopy openings and contain standing water exhibit this signature along with assorted wetland-vegetation signatures. Saturated soils show darker tones because of the nonreflectance of the soil-water component. Even when wetland basins are dry, the silt, clay, and other fine-grained materials hold more water than the upland soils hold, which results in a distinctive dark color because of the lack of infrared reflectance.

Vegetation characteristics help to identify wetlands. Wetland vegetation generally is more dense, more crowded, and more concentrated than upland vegetation. Wetland vegetation normally exhibits a higher degree of lushness, vigor, and intensity than does upland vegetation. Even wheat grown in a dry wetland basin has a distinctive signature; it is more vigorous because of extra moisture in the basin. Dead and dying vegetation in flooded wetland basins also has distinctive signatures. When physiographic positions are associated with the vegetative characteristics described above, wetland locations become more obvious on an aerial photograph (fig. 47).

Patterns, or the repetition of the spatial arrangement, of vegetative types also provide important clues in the identification of wetlands. Basins that have a semipermanently flooded center may have a seasonally flooded band around the center and a temporarily flooded outer band. Patterns are not restricted to vegetation—they can include drainage patterns and land-use patterns. Unplanted basins in farm fields might indicate wetlands; land-cover patterns such as ridges and swales help separate uplands and wetlands. When wetlands are being mapped, the photointerpreter closely checks areas indicated by swamp symbols as wetlands on USGS topographic maps and NRCS soil survey maps to ensure their possible inclusion as wetlands; such areas are considered wetlands unless strong evidence indicates otherwise.

A typical National Wetlands Inventory map consists of wetland boundaries added to a black-and-white version of a 1:24,000-scale USGS topographic base map. Wetlands are classified according to guidelines developed by Cowardin and others (1979). (See article "Wetland Definitions and Classifications in the United States" in this volume.) These wetland classifications are shown on the map as alpha-numeric codes that are identified in a map explanation at the bottom of the map. Many steps are involved in the production of a wetland map from selecting the sites for field verification to delineation, quality control, and production of the final map product (fig. 48). All National Wetlands Inventory photointerpreters are trained extensively in wetland identification, the FWS wetland classification system, and the field identification of wetland plants and soils in order to ensure the best quality, most accurate maps.

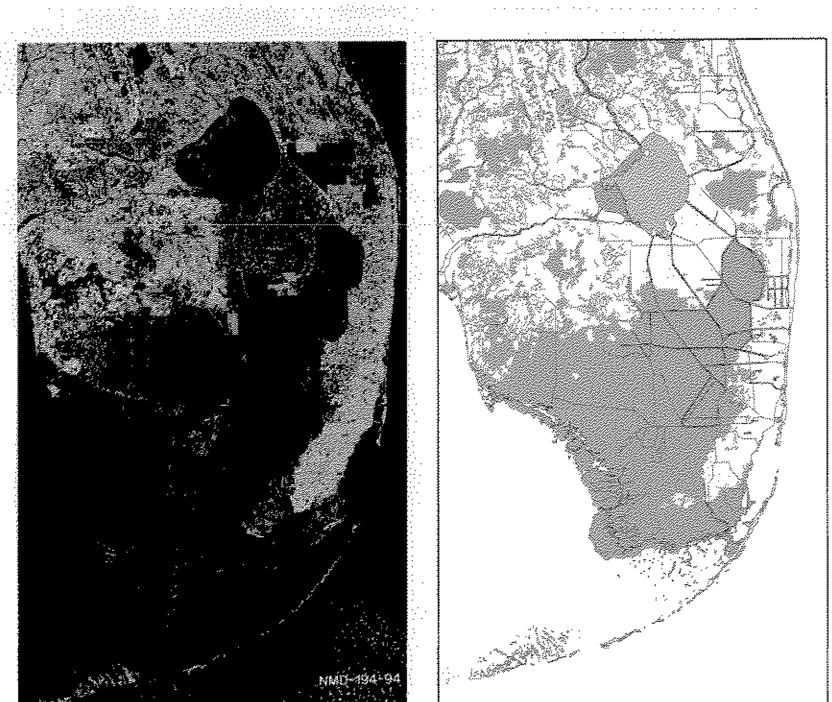


Figure 47. Wetland features such as water, vegetation, and soil are identified on an aerial photograph by their signatures (left), and these signatures are used to produce wetland maps (right). *(Source: U.S. Geological Survey, 1995 (left); T.E. Dahl, U.S. Fish and Wildlfie Service, unpub. data, 1992 (right).)*

STEPS IN PRODUCING NATIONAL WETLANDS INVENTORY MAPS

1. Determine project area.
2. Obtain source materials.
3. Prepare source materials (photo *A*).
4. Review photo interpretation and plan field trip (photo *B*).
5. Conduct a field reconnaissance of study area.
6. Make photo interpretation (photo *C*).
7. Check photointerpretation (quality control) (photo *D*).
8. Transfer photointerpreted data to base map (photo *E*).
9. Check transferred information (quality control).
10. Prepare copy of draft map for review.
11. Conduct review of draft maps.
12. Make changes to draft map manuscript (photo *F*).
13. Conduct final quality-control checks.
14. Produce final map for distribution (photo *G*).
15. Digitize the final map (photo *H*).

Figure 48. The sequence of steps in producing National Wetlands Inventory maps. *(Photographs A and E by Judy D. Fretwell, U.S. Geological Survey; all other photographs by Donald W. Woodard, U.S. Fish and Wildlife Service.)*

HOW AND WHERE TO GET NATIONAL WETLANDS INVENTORY MAPS

Maps of the National Wetlands Inventory can be acquired from 33 State-run distribution centers, 6 USGS Earth Science Information Center regional offices, or by calling the USGS national toll-free number: 1-800-USA-MAPS. Maps can also be viewed at the Library of Congress and the Federal Depository Library System and downloaded cost-free through the National Wetlands Inventory Home Page on the Internet at http://www.nwi.fws.gov. The six regional USGS Earth Science Information Centers provide online computer links to the National Wetlands Inventory map data base, which contains current information about the availability and production history of National Wetlands Inventory maps and digital data. Digital data are available in Digital Line Graph 3 (DLG3) optional or Geographic Resources Analysis Support System (GRASS) formats; latitude and longitude, State Plane Coordinates, or Universal Transverse Mercator (UTM) coordinate systems; and 9-track, 8-mm, or 1/4-inch cassettes in UNIX-TAR or ASCII tape formats. Other products available at cost include acreage statistics by quadrangle, county, or study area and color-coded wetland maps.

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Wetland Management and Research

Wetland Functions, Values, and Assessment

By Richard P. Novitzki[1], R. Daniel Smith,[2] and Judy D. Fretwell[3]

Wetlands, or the lack thereof, were a significant factor in the severe flooding in the Upper Mississippi and Missouri River Basins in the summer of 1993 (Parrett and others, 1993) (fig. 49). Damages associated with the flooding were undoubtedly worse than they would have been if flood-plain wetlands had still been in place. Human modification of the original wetlands (a common practice in the early part of this century) had destroyed the ability of the wetlands to modify flooding. (See the article "Effects of the Great Midwest Flood of 1993 on Wetlands" in this volume.) Flood control, however, is only one of the values that wetlands have for society. In order to protect wetlands, the public first must recognize the values of wetlands. People need to understand what is lost when a wetland is changed into an agricultural field, a parking lot, a dump, or a housing development. Understanding the functions of wetlands will make it easier to evaluate wetlands when other uses are considered.

RECOGNITION OF WETLAND FUNCTIONS AND THEIR VALUES

In the 1970's, scientists, ecologists, and conservationists began to articulate the values of wetlands. At a wetland conference in 1973, wetlands were acknowledged to be an important part of the hydrologic cycle (Helfgott and others, 1973). In 1977, participation at the first National Wetland Protection Symposium—attended by more than 700 people—demonstrated a growing interest in the value of wetlands and the need to protect them (Kusler and Montanari, 1978). At a Wetland Values and Management Conference in 1981, scientists defined the unique qualities of wetlands and developed a list of wetland functions (Richardson, 1981). In addition to the more commonly recognized habitat functions of wetlands, the scientists described hydrologic and water-quality functions. During the 1980's, participants at many more conferences and symposia expanded the understanding and appreciation of the values of wetlands (Kusler and Riexinger, 1986).

WETLAND FUNCTIONS DEFINED

Wetland functions are defined as a process or series of processes that take place within a wetland. These include the storage of water, transformation of nutrients, growth of living matter, and diversity of wetland plants, and they have value for the wetland itself, for surrounding ecosystems, and for people. Functions can be grouped broadly as habitat, hydrologic, or water quality, although these distinctions are somewhat arbitrary and simplistic. For example, the value of a wetland for recreation (hunting, fishing, bird watching) is a product of all the processes that work together to create and maintain the wetland.

Not all wetlands perform all functions nor do they perform all functions equally well. The location and size of a wetland may determine what functions it will perform. For example, the geographic location may determine its habitat functions, and the location of a wetland within a watershed may determine its hydrologic or water-quality functions (fig. 50). Many factors determine how well a wetland will perform these functions: climatic conditions, quantity and quality of water entering the wetland, and disturbances or al-

Not all wetlands perform all functions nor do they perform all functions equally well.

Wetlands are among the most productive habitats in the world.

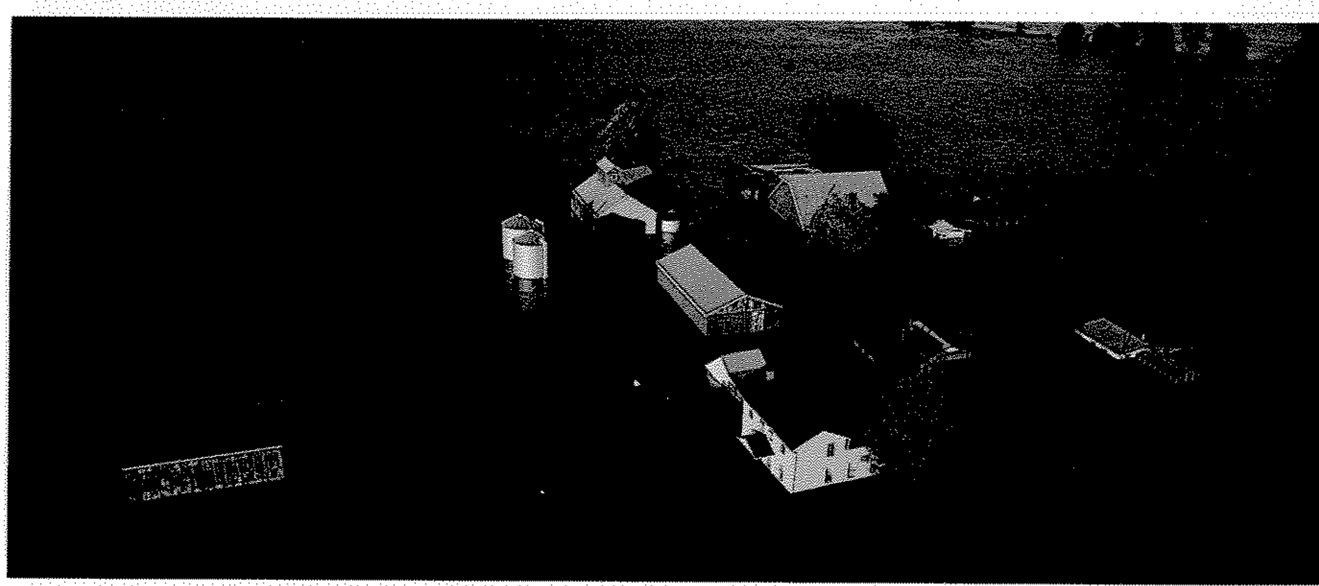
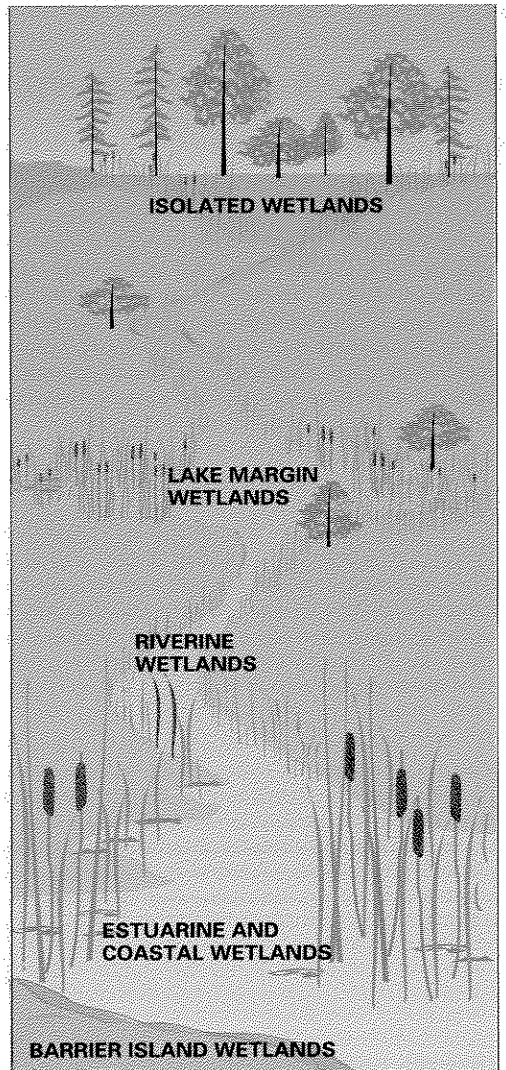


Figure 49. Flooding in the Upper Mississippi River Basin, summer 1993. *(Photograph © Cameron Davidson, 1993.)*

[1] ManTech Environmental Technology, Inc.
[2] U.S. Army Corps of Engineers.
[3] U.S. Geological Survey.



CHARACTERISTICS AND FUNCTIONS OF WETLANDS

Isolated Wetlands
1. Waterfowl feeding and nesting habitat
2. Habitat for both upland and wetland species of wildlife
3. Floodwater retention area
4. Sediment and nutrient retention area
5. Area of special scenic beauty

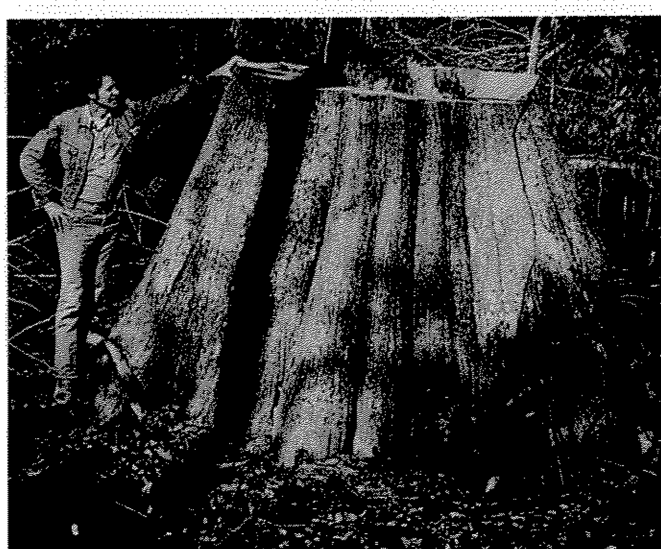
Lake Margin Wetlands
1. See "isolated wetlands" above
2. Removal of sediment and nutrients from inflowing waters
3. Fish spawning area

Riverine Wetlands
1. See "isolated wetlands" above
2. Sediment control, stabilization of river banks
3. Flood conveyance area

Estuarine and Coastal Wetlands
1. See "isolated wetlands" above
2. Fish and shellfish habitat and spawning areas
3. Nutrient source for marine fisheries
4. Protection from erosion and storm surges

Barrier Island Wetlands
1. Habitat for dune-associated plant and animal species
2. Protection of backlying lands from high-energy waves
3. Scenic beauty

Figure 50. Wetland functions depend upon the location of the wetland within a watershed. *(Source: Modified from J.A. Kusler, Our National Heritage: A Protection Guidebook. Copyright (c) 1983 by the Environmental Law Institute. Reprinted by permission.)*



Timber harvest in a bottom-land forested wetland. *(Photograph by R. Daniel Smith, U.S. Army Engineer Waterways Experiment Station.)*

Hay harvest in a prairie wetland. *(Photograph by Richard P. Novitzki, ManTech Environmental Technology, Inc.)*

teration within the wetland or the surrounding ecosystem. Wetland disturbances may be the result of natural conditions, such as an extended drought, or human activities, such as land clearing, dredging, or the introduction of nonnative species.

Perhaps wetlands are best known for their habitat functions, which are the functions that benefit wildlife. Habitat is defined as the part of the physical environment in which plants and animals live (Lapedes, 1976), and wetlands are among the most productive habitats in the world (Tiner, 1989). They provide food, water, and shelter for fish, shellfish, birds, and mammals, and they serve as a breeding ground and nursery for numerous species. Many endangered plant and animal species are dependent on wetland habitats for their survival. (See the article "Wetlands as Bird Habitat" in this volume.) Hydrologic functions are those related to the quantity of water that enters, is stored in, or leaves a wetland. These functions include such factors as the reduction of flow velocity, the role of wetlands as ground-water recharge or discharge areas, and the influence of wetlands on atmospheric processes. Water-quality functions include the trapping of sediment, pollution control, and the biochemical processes that take place as water enters, is stored in, or leaves a wetland. (See article "Wetland Hydrology, Water Quality, and Associated Functions" in this volume for more information on hydrologic and water-quality functions.)

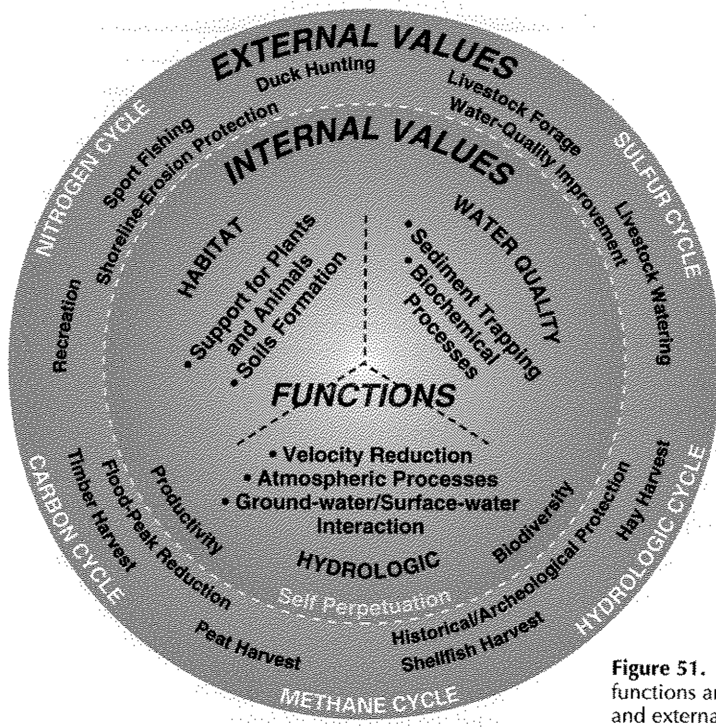


Figure 51. Wetland functions and internal and external values.

WETLAND VALUES DEFINED

If something has "value," then it is worthwhile, beneficial, or desirable. The value of a wetland lies in the benefits that it provides to the environment or to people, something that is not easily measured. Wetlands can have ecological, social, or economic values. Wetland products that have an economic value, such as commercial fish or timber, can be assigned a monetary value. True wetland value, however, goes beyond money. How much value does one place on the beauty of a wetland or its archeological significance? Wetland values are not absolute. What is valuable and important to one person may not be valuable to another person. As an example, the value of a wetland as duck habitat may be important to the hunter or birdwatcher but not to the farmer who owns the land.

"While wetland functions are natural processes of wetlands that continue regardless of their perceived value to humans, the value people place on those functions in many cases is the primary factor determining whether a wetland remains intact or is converted for some other use" (National Audubon Society, 1993). In addition, values assigned to wetland functions may change over time as society's perceptions and priorities change. The values that benefit society as a whole tend to change slowly; however, the values assigned by individuals or small groups are arbitrary, and most are subject to rapid and frequent change and may even conflict. For example, timber production may be improved by draining a wetland site, whereas waterfowl production may be improved by impounding more water. Society may have to resolve conflicts regarding the management or preservation of wetlands and their functions. Furthermore, society may have to choose among wetland functions that benefit individuals or small groups, that are of value to most of society, or that are important to the maintenance of the wetland itself.

Wetland functions have value on several levels—internal, local, regional, and global. All wetland functions are internal, but the values or benefits of wetland functions can be internal or external to the wetland (fig. 51). Functions that provide internal values are the functions that maintain or sustain the wetland and are essential to the continued existence of the wetland. Conversely, many functions have external values that extend beyond the wetland itself. On a local scale, wetlands affect adjacent or nearby ecosystems, for example, by reducing flooding in downstream communities or by removing nutrients from wastewater. However, the broadest influence of wetland functions is global. Wetlands are now thought to have a significant effect on air quality, which is influenced by the nitrogen, sulfur, methane, and carbon cycles. In addition, migrating birds are dependent upon wetlands as they travel.

A system of wetland assessment is necessary to ensure that the most valuable wetlands are protected.

PURPOSE OF WETLAND ASSESSMENT

Many times when decisions are made about development of an area, such as the selection of a site for a large commercial or industrial facility, the choice of sites is not between a wetland or an upland, but between wetlands. In areas that have many wetlands, all alternative sites or routes for roads for a major facility may involve the destruction or alteration of wetlands. In such cases, legal requirements commonly exist that require the replacement of destroyed wetlands. Even when a choice must be made between a wetland site and an upland site, the upland site may have great value to the community. Managers, planners, regulators, and even the general public have long

The WET evaluates functions and values in terms of effectiveness, opportunity, social significance, and habitat suitability.

felt the need to have in place a system of assessment or evaluation that would make the choices clearer and ensure that the most valuable wetlands are preserved. Such an evaluation system could be based entirely or partly on wetland function if values could be assigned to individual functions.

Wetland assessment methods have been or are being developed that assign numerical values to wetland functions. Some methods assign values on the basis of the benefits to the wetland itself by considering the question: How important is this function in terms of maintaining this particular wetland? Other methods assign values on the basis of the benefits to surrounding ecosystems or to humans. The types of questions considered in this approach are as follows: How important is this function to environmental quality downstream? How does this function benefit society? This latter assessment method allows for the comparison of the worth of one wetland to that of another wetland.

The development of a single method for assessing the functions of wetlands or for assigning values to the functions of wetlands is not a simple task. Indeed, probably no one method will satisfy all needs. However, assessing each function of a wetland and then assigning a value to each function is a step toward the protection of sensitive wetlands. Furthermore, an evaluation system that provides the basis for comparing wetlands would facilitate mitigation for unavoidable wetland losses, would provide a tool for determining the success (or failure) of programs and policies intended to protect or manage wetland resources, and would assist in identifying long-term trends in the condition of wetland resources.

WETLAND ASSESSMENT METHODS

The three wetland assessment methods described herein are representative of the methods that are available or are being used by wetland managers and planners. The Wetland Evaluation Technique was developed for the Federal Highway Administration and has been used widely. It assigns values to specific functions of individual wetlands. The Environmental Monitoring Assessment Program—Wetlands was developed by the Environmental Protection Agency. It is presented here as an example of a program that focuses on determining the ecological condition of a population of wetlands in a region. It does this by comparing the function of a statistical sample of wetlands to reference wetlands in the region. The Hydrogeomorphic approach is being developed by the U.S. Army Corps of Engineers for assessing wetland functions. It combines features of the other two methods by measuring the functions of individual wetlands and also by comparing them to functions performed by other wetlands.

Wetland Evaluation Technique (WET)

The WET is a comprehensive approach for evaluating individual wetlands that was developed in 1983 (Adamus, 1983; Adamus and Stockwell, 1983) and revised in 1987 under the auspices of the U.S. Army Corps of Engineers (Adamus and others, 1987). The WET considers wetland functions to be the physical, chemical, and biological characteristics of a wetland. It assigns wetland values to the characteristics that are valuable to society. The following functions are assigned values by WET:

- Ground-water recharge
- Ground-water discharge
- Floodflow alteration
- Sediment stabilization
- Sediment/toxicant retention
- Nutrient removal/transformation
- Production export
- Wildlife diversity/abundance
- Aquatic diversity/abundance
- Recreation
- Uniqueness/heritage

The recreational pleasures of a wetland are captured in this photo at Horicon Marsh, Wis. *(Photograph by Phillip J. Redman, U.S. Geological Survey.)*

The WET evaluates functions and values in terms of effectiveness, opportunity, social significance, and habitat suitability. Effectiveness assesses the capability of a wetland to perform a particular function. For example, a wetland that has no outlet is assigned a high value for sediment retention, whereas a wetland just downstream from a dam is assigned a low value. Opportunity assesses the potential for a wetland to perform a specific function; for example, a wetland in a forested area that has no potential sediment sources would be assigned a low opportunity value for sediment retention. Social significance assesses the value of a wetland in terms of special designations (does it have endangered species?), potential economic value (is it used regularly for recreational activities?), and strategic location (is it in a State where very few wetlands of its type remain?). The WET uses "predictors" that relate to the physical, chemical, and biological characteristics of the function being evaluated. As an example, the presence or absence of a constricted outlet from a wetland could be used to predict whether the wetland might be effective in storing floodwaters. In addition, WET can be used to assess the habitat suitability for waterfowl and wetland-dependent birds, fish, and invertebrates.

The WET approach was designed to provide a balance between costly, site-specific studies and the "best professional judgment" approach, which is less costly but lacks reproducibility. The WET method is intended to be used by any environmental professional, so that an engineer can evaluate biological functions or a biologist can evaluate hydrologic functions. First, information resources are obtained for the wetland, the area surrounding the wetland, and the area downstream from the wetland. Then a series of questions is answered about the wetland's watershed, topography, vegetation, and other features. By progressing next through a series of flow charts (or an available computer software package), an evaluation can assign a probability rating of "high," "moderate," or "low" to each of the functions listed above (except for recreation) and a habitat suitability rating for waterfowl, fish, and other wildlife (Adamus, 1988). The probability rating is an estimate of the "likelihood" that a wetland will perform a function on the basis of its characteristics. It does not estimate the degree or magnitude to which a function is performed. Recreation is not evaluated because no scientific basis exists for making an objective assessment without extensive data collection at the site.

The WET approach probably has been applied to nearly every type of wetland in every State; however, it has proved to be unwieldy to use. For most users, the need to be able to apply this method to every wetland in every part of the United States makes the system unnecessarily cumbersome. For example, most users are interested in a local area and prefer not to enter data repeatedly for local characteristics that are unlikely to change, as is required in the WET approach. In order to refine the method for specific regions and to refine the thresholds among the low, medium, and high values, Adamus (1988) intended that regional versions and five different levels of WET be developed, neither of which has happened. Despite its shortcomings, however, WET continues to be used by those who are familiar with it. Furthermore, much of the data generated by its application could be used to create data bases that would simplify its use and would improve its regional application.

EMAP—Wetlands identifies "indicators" of condition, standardizes methods of measurement, and establishes a national network.

Environmental Monitoring Assessment Program—Wetlands (EMAP—Wetlands)

In 1988, the Environmental Protection Agency initiated the Environmental Monitoring Assessment Program (EMAP) in order to provide improved information on the status and trends in the condition of the Nation's ecological resources. The wetlands part of EMAP was intended to develop an approach for assessing the condition (how well a wetland is performing its functions) of different types of wetlands in a region and in the Nation as a whole (Novitzki,

Sheep foraging at a wetland near Bridgeport, Calif. *(Photograph by A.S. Van Denburgh, U.S. Geological Survey.)*

1994; Novitzki and others, 1994). The near-term objectives of the program were to conduct research in order to identify "indicators" of wetland condition, to standardize methods of measurement, and to establish a national network for monitoring wetlands at regional scales and over long periods (decades). In some places, it is impossible or impractical to measure wetland functions directly; therefore, characteristics or "indicators" are measured, and these indicate how well certain functions are being performed by the wetland. For example, the number of waterfowl per acre can be calculated from actual field measurements and then can be used as an indicator of how well a wetland is performing its waterfowl habitat function.

The HGM approach represents a combination of the WET and EMAP—Wetlands approaches

The EMAP—Wetlands program was intended to have three phases. First, pilot studies were to be conducted to evaluate the ability of selected indicators to make a distinction between healthy and degraded wetlands. Next, regional demonstrations were to be conducted by using some of the best indicators from the pilot studies. These demonstrations would confirm the ability of the program to assess the condition of a specific type of wetland in a specific region. Finally, the program would be implemented to monitor the condition of a specific wetland type in a region. Only Phase I has been conducted.

Data from pilot and demonstration studies in Phase I are being analyzed to develop preliminary indices of signs of the health of a wetland. One index will be for biological integrity, which combines indicators of healthy plant and animal communities. Biological characteristics of the sampled wetlands will be compared with those of the most unaltered wetlands of the same type in the region, known as reference wetlands. This comparison is based on the assumption that the least altered wetlands have sustainable biological integrity.

Other likely indices will be related to the following: habitat integrity (how does the population of waterfowl, finfish, or shellfish in sampled wetlands compare with that in reference wetlands?), hydrologic integrity (how similar is the hydrologic regime in the sampled wetlands to that in reference wetlands?), and water-quality improvement (how do sediment trapping and other water-quality processes in sampled wetlands compare with those in reference wetlands?). Wetland health may be evaluated either by similarity (how similar are sampled wetlands to reference wetlands?) or by biological criteria (are the sampled wetlands above or below a level determined from measurements obtained in the reference wetlands?). The comparison of the condition of sampled wetlands with the condition of reference wetlands provides a means for telling the difference between changes that result from long-term changes in climate (both sampled wetlands and reference wetlands will be affected) and changes that happen because of management actions, regulatory policy, or other human factors that affect wetlands (only the sampled wetlands will be affected).

Pilot studies of salt marshes in the Gulf of Mexico and prairie pothole wetlands of the Midwest have been completed. Results of these studies have been evaluated to identify the indicators that most effectively reveal the difference between healthy and degraded wetlands. In the salt marshes, the indicators that seem to hold the greatest promise (Turner and Swenson, 1994) are as follows:

- Ratio of vegetated areas to open water
- Number of plant species (or the diversity of plant species)
- Biomass (production of plant material per unit area)
- Amount of organic matter in soil
- Salinity

Serene beauty is provided by this restored wetland in Montana. *(Photograph by Edith B. Chase, U.S. Geological Survey.)*

In prairie pothole wetlands, indicators of the health of a wetland that seem to hold the greatest promise at the local level (L.M. Cowardin, U.S. Fish and Wildlife Service, oral commun., 1994) are:

- Amount of developed land in the surrounding upland
- Rates of increase and decrease in the number of water-filled basins or in the area of water surface between April (spring thaw) and August (end of summer)
- Ratio of temporary to seasonal to semipermanent wetlands

At the level of the individual wetland ecosystem, other promising indicators (L.M. Cowardin, oral commun., 1994) are:

- Diversity of plant species
- Number and types of species of large invertebrates
- Range of water-level fluctuation
- Sedimentation rate

Hydrogeomorphic Approach (HGM)

In 1990, the U.S. Army Corps of Engineers began developing the Hydrogeomorphic Approach (HGM) as a way to provide a foundation for assessing the physical, chemical, and biological functions of wetlands (Brinson, 1993; Smith and others, 1995). The program, still being developed, is intended to revise and simplify the WET approach described above (Adamus and others, 1987), as well as make it more applicable to specific regions. The WET procedure develops a profile of specific characteristics (predictors) for an individual wetland, and these are used to assess the degree of effectiveness of the different functions of the wetland. The HGM approach compares the characteristics of a specific wetland with the characteristics of a group of wetlands (reference wetlands) in the region, and this information is used to assess the degree to which the individual wetland is performing selected functions. Thus, the HGM approach represents a combination of the WET and EMAP—Wetlands approaches. Wetland characteristics to be evaluated by HGM are limited to those that are important in the specific region and hydrogeomorphic setting. Hence, different characteristics will be identified and evaluated for different hydrogeomorphic settings, such as closed basins in the Midwest (for example, prairie pothole wetlands), river-edge wetlands in the Southeast (for example, bottom-land hardwood wetlands), and coastal wetlands (for example, salt marshes).

In the HGM approach, local wetland scientists or managers identify the functions that are performed by wetlands in a specific hydrogeomorphic setting in that region. Also, they identify wetland characteristics (indicators), such as plant communities, plant species, and density of stems, that suggest whether or not a wetland is performing a specific function, such as slowing the flow velocity of floodwater. Next, the value of each function is determined by measuring the degree to which that function is likely to be performed. This is based on the characteristics of the indicators. For example, if lines of debris are selected as an indicator that a wetland has been flooded, their altitude may be used to determine how deep the water may have been during flooding and thus how much water may be stored in the wetland. The nature of the debris lines also may suggest the velocity of the water as it moved through the wetland. For example, small leaves and twigs suggest slow-moving water, small branches suggest somewhat swifter water, and large branches and tree trunks suggest very high velocities. Sediment deposits observed at the site may suggest the depositional characteristics. For example, no sediment deposits suggest little deposition, thin silt deposits suggest that slow-moving water was sustained for long periods, and gravel and cobble deposits might suggest that water was flowing rapidly when it entered the site but then slowed significantly at the site.

A wetland assessment provided by the HGM approach will likely be a "site profile" that lists the site characteristics that are related to identified wetland functions. This profile then will be compared with characteristics of the reference wetlands (all wetlands in the region in the same geomorphic class) in order to rank the site. A data base that contains profiles of wetland characteristics (indicators of wetland functions) for each wetland type (hydrogeomorphic class) will be established for each region. These data will define the range of characteristics found in these wetlands.

At present (1995), the HGM approach is in development and has not been released to the public. Field tests of this assessment method have been conducted in river-edge wetlands in the Pacific Northwest, the Northeast, the Rocky Mountains, the Southwest, and the Southeast; in coastal wetlands in the Pacific Northwest, the North and South Atlantic States, and the gulf coast States; and in closed-basin wetlands in the Midwest. Data and insights derived from these tests are being compiled and will be evaluated in regional workshops. Following those evaluations, manuals of draft HGM methods will be prepared and presented for comment and review in regional workshops.

CONCLUSIONS

If any hope remains for preserving the Nation's wetland resources, it depends upon obtaining public support. Public support can be won if scientists can explain clearly how wetlands function, how they interact with their surroundings, and how their functions can benefit society. Wetlands have come under intensive scientific study only during the last two decades. Techniques of wetland evaluation will improve as scientists gather more information about the processes that take place in wetlands and about the similarities and differences among the functions of different types of wetlands. In order to develop public support and to encourage enlightened policy decisions and regulations, it is critical to create and maintain a data base of wetland characteristics in which the data are reliable, comparable, and repeatable at periodic intervals in order to monitor long-term trends.

More than one approach to wetland evaluation is possible, as illustrated by the examples discussed above. Wetland functions and their values to humans and other living matter may be assessed for an individual wetland by using approaches such as WET or

It is critical to create and maintain a data base of wetland characteristics in which the data are reliable, comparable, and repeatable.

HGM. After this, they can be compared with other natural wetlands in a region by using the HGM approach. Both WET and HGM can be used to determine the amount of mitigation required to offset unavoidable wetland loss, as well as to evaluate the degree of success of individual mitigation projects. (See article "Wetland Protection Legislation" in this volume for further discussion of mitigation.) The EMAP—Wetlands approach suggests that it might be possible to examine the condition (pristine or degraded) of a population of wetlands in a specified area. Periodic reevaluation of this population of wetlands might be used to determine trends in their condition and to identify the effects of broad policy decisions (such as "no net loss"), programs (such as mitigation banking where wetlands are created or restored to offset losses of other wetlands), or natural phenomena (such as climate change).

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Restoration, Creation, and Recovery of Wetlands
Wetland Restoration and Creation

Mary E. Kentula[1]

The benefits of restoration of degraded or destroyed wetlands and creation of new wetlands has only recently been recognized. As the population has expanded across the Nation during the past few centuries, wetlands have been drained and altered to accommodate human needs. These changes to wetlands have directly, or indirectly, brought about changes in the migratory patterns of birds, local climate, and the makeup of plant and animal populations. In the past, people used wetland plants and animals for shelter and food. More recently, people have become more aware of other benefits that wetlands provide—water-quality improvement, flood attenuation, esthetics, and recreational opportunities. Now, it is recognized that numerous losses are incurred when a wetland is damaged or destroyed. Restoration and creation can help maintain the benefits of wetlands and their surrounding ecosystems, and at the same time accommodate the human need for development.

Wetland restoration rehabilitates a degraded wetland or reestablishes a wetland that has been destroyed. Restoration takes place on land that has been, or still is, a wetland. A term commonly associated with restoration is "enhanced." An enhanced wetland is an existing wetland that has been altered to improve a particular function, usually at the expense of other functions. For example, enhancing a site to increase its use by a particular species of bird commonly limits its use as habitat for other species. (For information on functions of wetlands see the articles "Wetland Hydrology, Water Quality, and Associated Functions" and "Wetland Functions, Values, and Assessment" in this volume.)

Wetland creation is the construction of a wetland on a site that never was a wetland. This can be done only on a site where conditions exist that can produce and sustain a wetland. Consequently, creation is more difficult than restoration. A term commonly associated with wetland creation is "constructed." A constructed wetland is a wetland created specifically for the purpose of treating wastewater, stormwater, acid mine drainage, or agricultural runoff (Hammer, 1989). As used in this article, "project wetland" refers to restored or created wetlands. (For a more complete discussion of the meaning of these terms and others associated with restoration and creation, see Lewis, 1990.)

CHALLENGES OF RESTORATION AND CREATION

Ecological issues and physical limitations are important factors to consider when planning for wetland restoration or creation. The relative merits of destroying the function of an existing wetland, or other ecosystem, in exchange for another wetland function involves the consideration of numerous questions such as: (1) Which is more important, the existing or the replacement function? (2) Will the proposed wetland increase wildlife diversity? (3) Is the increased diversity worth the loss of habitat of any endangered species? Questions of this type always arise during planning for wetland restoration and creation.

A well-documented example of a physical limitation associated with restoring a wetland can be seen along the shoreline of the Salmon River Estuary, Oreg. (Frenkel and Morlan, 1990, 1991). In the past, many high marsh wetlands along the Pacific coast were diked to remove them from tidal action. After the area was diked, the wetlands dried up and the land was used for pasture. In 1978, in an effort to restore the Salmon River Estuary to its original condition, two dikes were removed to allow the original wetlands to reestablish themselves. However, after 10 years, the resulting wetlands (fig. 52) were not typical of other high marshes along the estuary. The land behind the dikes had subsided over time, and the restored wetlands were more typical of wetlands at lower elevations nearer the estuary (low marsh). Although the wetlands continue to evolve as sediments are trapped and deposited by the vegetation (thus raising the elevation), it might take another 50 years for the restored wetlands to become similar again to the original high marsh (Frenkel and Morlan, 1991). The time required and the ability to develop a fully functional soil system in project wetlands may be major determinants of the eventual acceptance or rejection of restoration and creation as management options.

It is difficult to make a definitive statement about the ability to replace wetland functions. Goals for restoration and creation projects seldom are stated and information on the existing functions of the wetlands seldom are documented. This is due, in part, to the difficulty and expense of quantifying wetland functions. Also, responsible monitoring during construction and after completion of the project wetland is uncommon. Most information available on project wetlands is in the form of qualitative case studies.

Wetland alterations have brought about changes in the migratory patterns of birds, local climate, and make up of plant and animal populations.

Restoration and creation can help maintain the benefits of wetlands and accommodate the human need for development.

Figure 52. View of a restored salt marsh in the Salmon River Estuary on the Oregon coast. *(Photograph courtesy of the EPA Wetlands Research Program.)*

[1] U.S. Environmental Protection Agency (EPA).

DESIGNING FOR SUCCESS

Much of the written material on wetland restoration and creation deals with "project design." Project design considers a large number of site-specific, interdependent factors that determine the structure and function of a wetland. Although there is no "cookbook" for restoring or creating wetlands, documents describing general approaches to restoration and creation and the conditions conducive to project success are available (Garbisch, 1986; Marble, 1990; Pacific Estuarine Research Laboratory, 1990; Hammer, 1992; Maynord and others, 1992). Elements common to wetland project design are site-selection criteria, hydrologic analysis, water source and quality, substrate augmentation and handling, plant material selection and handling, buffer zones placement, and long-term management. A brief overview of each element is presented here in a sequence similar to that followed in project planning.

Benefits can extend beyond the wetland if care is taken in site selection.

Site selection.—Sites for project wetlands often are selected on the basis of available land, or on policies that require wetlands to be restored or created to compensate for nearby wetland losses (mitigation). A wetland's structure, function, and ability to persist over time are greatly influenced by its location. Wetlands in settings with limited human influence can differ greatly in structure and function from wetlands in settings dominated by human activities. Therefore, the present and projected land uses of the surrounding area are a consideration when selecting the site. The characteristics of existing wetlands, in the same general area, or in an area with similar land uses, can be used as models for what might be expected of the project wetland. Benefits that extend beyond the wetland itself can be derived from the placement of a wetland if care is taken in site selection. For example, restoration of riverbank wetlands between agricultural land and a stream can improve downstream water quality (Olson, 1992).

Hydrologic analysis.—Hydrologic conditions probably are the most important determinants of the type of wetland that can be established and what wetland processes can be maintained (Mitsch and Gosselink, 1993). Elements of site hydrology that are important to maintaining a wetland are inflows and outflows of ground water and surface water, the resulting water levels, and the timing and duration of soil saturation or flooding.

Hydrologic conditions probably are the most important determinants of wetland types and processes.

One factor influencing hydrology is the configuration of the basin (depression) containing the wetland. The position of the basin surface relative to the water table influences the degree of soil saturation and flooding. To ensure that standing water is present year round, many project wetlands are excavated so that the deepest part of the basin is below the lowest anticipated water level. The slope of the basin banks determines how much of the site will be vegetated and by what kinds of plants (fig. 53). This is because the slope determines how far the substrate (soil or rock material that forms the surface of the basin) will be from water and how much of the substrate has the necessary conditions of wetness for specific plant species (Hollands, 1990). The ability to maintain the desired plant community, therefore, is ultimately dependent on the hydrology of the site. In a properly constructed freshwater marsh, the lowest point of the wetland will be inundated to a depth and for a period long enough that emergent vegetation can persist, but not so long as to destroy the plants.

Water source and quality.—Although it is commonly acknowledged that site hydrology is a major determinant of the success or failure of wetland restoration or creation, the influence of water quality often is ignored. Inputs of chemicals from the surrounding landscape can overwhelm a wetland's ability to improve water quality and can change the characteristics of the site. For example, deicing salts are used extensively along highways and, if they enter a wetland, can alter the productivity and composition of its plant community, possibly favoring nuisance species such as purple loosestrife (Niering, 1989).

Substrate augmentation and handling.—Wetlands are characterized by hydric soils, which develop as a result of an area being saturated, flooded, or ponded long enough during the growing season to develop anaerobic (oxygen-deficient) conditions (U.S. Soil Conservation Service, 1991) (fig. 54). Most of the chemical reactions in wetlands take place in the soils, where most chemicals are stored (Mitsch and Gosselink, 1993). The soils of project wetlands are receiving increased attention as studies link substrate characteristics to ecological function. Although a created wetland may be structurally similar to a natural wetland, its hydrology may differ greatly from that of the natural wetland if the permeability of the substrates differ (O'Brien, 1986). In addition to differences in permeability, soils in project wetlands commonly have a smaller amount of organic matter than soils in similar natural wetlands. Because organic matter in soils stores nutrients that are critical to plant growth (Pa-

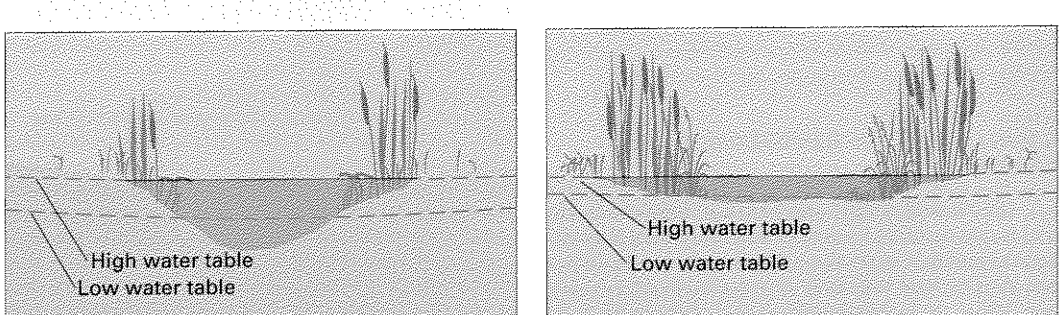

Figure 53. The relative position of a basin substrate, the water table, and differences in vegetation resulting from the degree of basin slope.

cific Estuarine Research Laboratory, 1990), the smaller amounts of organic matter in soils of project wetlands may limit plant growth (Langis and others, 1991). Augmenting, or mulching, the substrate of project wetlands with materials from a "donor" wetland can increase soil organic matter and provide a source of needed plant species, microbes, and invertebrates. Mulching makes the substrate more conducive to rapid revegetation by reducing the evaporation of pore water, runoff, soil loss and erosion, and surface compaction and crusting (Thornburg, 1977). Mulching also can cause problems such as the introduction of unwanted plant species.

Plant material selection and handling.—Vegetation is the most striking visual feature of a wetland. Because of the unique and stressful conditions that develop in wetlands, varying from long periods of flooding to periodic drying, plants and animals found there have developed distinctive mechanisms to deal with these stresses and conditions. It is important to recognize the constraints of this unique environment when planning a project wetland. Plant communities established in project wetlands will fare better if they closely resemble communities in similar, local wetlands. To increase the likelihood of successful colonization, Garbisch (1986) suggests that project managers:

- Select herbaceous species that rapidly stabilize the substrate and that have potential value for fish and wildlife
- Select species that are adaptable to a broad range of water depths. A survey of vegetation at wetlands of the type being created or restored can identify the conditions of "wetness" needed by species
- Avoid choosing only those species that are foraged by wildlife expected to use the site—muskrats and geese have been known to denude sites
- Avoid committing significant areas of the site to species that have questionable potential for successful establishment

In addition, Stark (1972) suggests the selection of "low maintenance" vegetation.

Buffer zone placement.—Protective measures are needed for many restored and created wetlands, particularly in urbanized areas. This protection can take the form of an undeveloped, vegetated band around the wetland; a fence or barrier; or a lake or sediment basin. This buffer between the wetland and surrounding land is desirable; however, the characteristics of an appropriate vegetated buffer are not well defined. Although composition is important, width is the most frequently cited characteristic of an adequate buffer zone. Requirements for both composition and width are dependent upon the adjacent land uses, their potential effect on the functions of the wetland, and the requirements of the animals that will use the wetland and buffer area. Buffers are used to:

- Deter predators from entering wetlands
- Trap and prevent undesirable materials from entering the wetland through runoff from the surrounding landscape
- Provide habitat for wildlife that depend on uplands in addition to wetlands for part of their life cycle

Long-term management.—Careful monitoring of newly established wetlands and the ability to make mid-course corrections are critical to long-term success. However, few project sponsors have been willing to assume long-term responsibility for managing these new systems (Kusler and Kentula, 1990b). Because of this, project wetlands that are designed to be self-sustaining or self-managing will have the best chance of survival. The installation of control structures, such as tide gates or pumps, that will require maintenance and are subject to vandalism could be disadvantageous to the life of the project wetland.

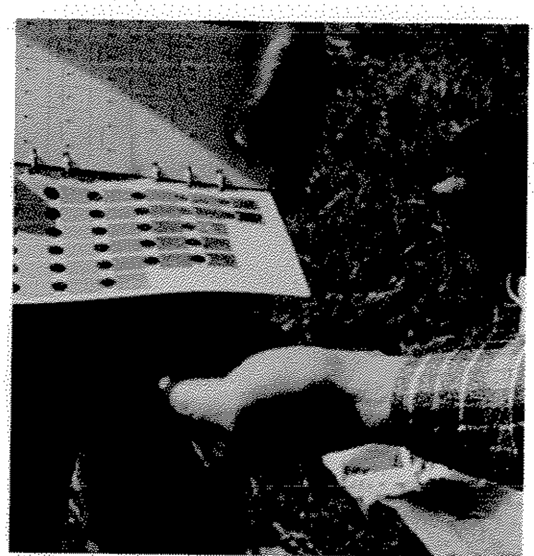

Figure 54. Scientist checking to see if a soil sample has the unique coloration typical of wetland (hydric) soils. *(Photograph courtesy of the EPA Wetlands Research Program).*

Chemicals from the surrounding landscape can overwhelm a wetland's ability to improve water quality.

EVALUATION OF SUCCESS

One of the most vexing aspects of wetland restoration and creation projects is defining success, primarily because there is no generally accepted definition. This is true for many reasons—lack of clearly stated objectives, lack of long-term monitoring (Kusler and Kentula, 1990b), and the subjective point of view of the definer (Roberts, 1993). The vast majority of project wetlands are ecologically young—10 years of age or less. The lack of information on ecologically mature projects limits the ability to predict whether or not the functions of project wetlands can replace the functions of natural wetlands. Nevertheless, the results of ongoing research and good professional judgment can be used to provide insight into the selection of projects that have a high probability of success.

Various attempts have been made to define success criteria for wetland projects. The earliest criteria assumed that if conditions were correct for the establishment of wetland vegetation, then other ecological functions would either be present or develop over time. Now, it is known that a site "green" with vegetation does not necessarily mean success, and the standards by which projects are judged are more likely to be tied to wetland functions.

Plants in project wetlands fare better if they closely resemble those in similar, local wetlands.

The Wetlands Research Program of the U.S. Environmental Protection Agency (EPA) is developing an approach to establish quantitative performance criteria for project wetlands. In this approach, groups of natural wetlands serve as reference sites against which project wetlands are judged. For example, Zedler (1993) uses reference data from natural marshes being used by clapper rails (an indigenous bird species) to define criteria that can be used to judge the suitability of restored and created habitat for the birds. Older project wetlands also are used as reference sites against which to judge newer project wetlands, both to verify that development is as expected and to identify developmental patterns that may have resulted from changes in project design (Kentula and others, 1992). This approach is designed to produce results that are regionally applicable to wetland protection and management.

It is still uncertain if a full suite of wetland functions can be replaced.

One tool for comparing the characteristics of project wetlands with similar, naturally occurring wetlands is a performance curve (fig. 55). Functions in a group of restored wetlands can be expected to increase gradually with time to a point of maturity at which time the level of function has stabilized. The mean level of function in mature project wetlands is generally less than that for natural wetlands. Rate and time of maturation and functional level at maturity will differ from project to project, depending on the type of wetland being restored. The curve provides information on when to monitor, how restored wetlands typically develop, and when project goals have been met. Changes in the characteristics of project wetlands can be expected in response to the maturation process, but also in response to changes in the environment. Information on the development of project wetlands and similar natural wetlands helps managers determine whether an observed change is typical for a particular year or stage of development.

Over time, successful project wetlands can be expected to become similar to comparable natural wetlands. A comparison of plant diversity on project wetlands and similar natural wetlands in Oregon (Kentula and others, 1992), Connecticut (Confer and Niering, 1992), and Florida (Brown, 1991) showed that, although the level of diversity differs with each project, diversity tends to be higher on each project wetland than on its natural counterpart. The type of wetland studied was a pond with a fringe of freshwater marsh (fig. 56). If a project wetland develops as hoped and expected, after 2 to 5 years it probably will have a plant diversity greater than or equal to that of similar natural wetlands. As competition for space and resources increases and the plants more completely cover the site, the diversity usually decreases and the plant community tends to become more like that of a mature site.

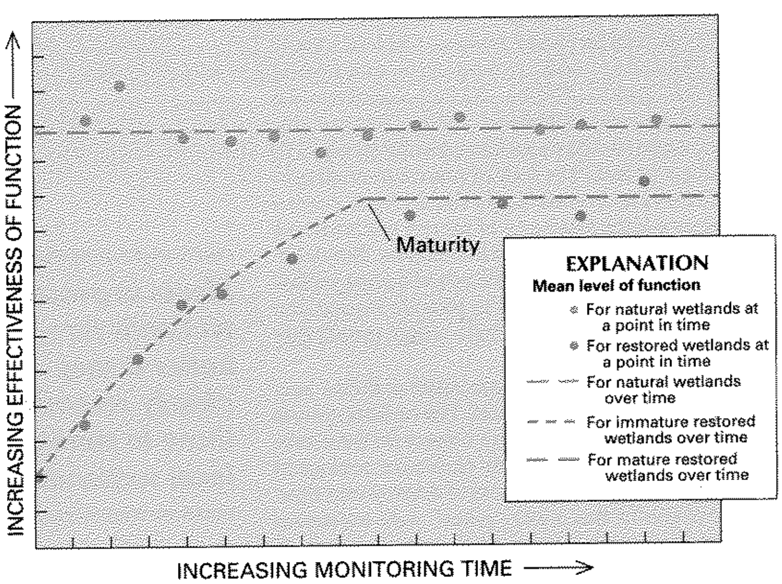

Figure 55. Typical performance curve illustrating the comparison of groups of natural wetlands and restored wetlands of the same type and similar size in the same land-use setting. *(Source: Modified from Kentula and others, 1992.)*

STATUS OF THE SCIENTIFIC KNOWLEDGE OF RESTORATION AND CREATION

Current scientific knowledge about successful wetland restoration and creation has been documented in "Wetland Creation and Restoration: The Status of the Science" (Kusler and Kentula, 1990a). Although the literature on wetland restoration and creation has increased since the publication of that book, the general assessment presented still applies. Key points from the Executive Summary (Kusler and Kentula, 1990b) are discussed below. (Additional information on restoration of aquatic systems, including wetlands, can be found in a recent publication by the National Research Council Committee on Restoration of Aquatic Ecosystems, 1992.)

The status of scientific knowledge about wetland restoration and creation differs by wetland function, type, and location. It is still uncertain if the full suite of functions provided by a particular wetland type can be replaced. Full functional replacement has not yet been demonstrated. In the case of specific functions, the most is known about replacement of flood storage and waterfowl habitat, and the least is known about water-quality-improvement and ground-water-associated functions. The more complex the hydrology and ecology of a system, the more difficult it is to restore the system. Complete restoration might be impossible in some systems.

With respect to types and locations of wetlands, the most is known about restoration and creation of intertidal salt marshes along the coasts of the United States, in particular, the tall cordgrass marshes of the Atlantic coast. However, these salt marshes comprise only about 5 percent of the total wetland area of the Nation and are only a small part of the marine and estuarine wetlands.

Much less is known about restoration and creation of inland freshwater wetlands, such as ponds, forested wetlands, or bogs and fens. Among these wetlands, most is known about restoration and creation of those dominated by open water, such as ponds, and the associated herbaceous vegetation. Much less is known about replacing forested wetlands because of the time needed for woody vegetation to mature. Experts agree, however, that the ecosystems that are least likely to be successfully replaced are bogs and fens. These are the wetlands with deep organic soils that have developed over thousands of years and that have hydrologic conditions that are difficult, if not impossible, to duplicate.

FEDERAL AGENCY RESEARCH ON WETLAND RESTORATION AND CREATION

Several Federal agencies have missions, and therefore conduct research activities, that involve wetlands. This section presents a brief overview of Federal research on wetland restoration and creation. [For more information on wetland research by Federal agencies, see the publications of the Wetlands Research Program of the U.S. Army Corps of Engineers (Corps) and the article "Wetland Research by Federal Agencies" in this volume.] The Corps has been leading an effort to provide a reference source on current wetland research being conducted by Federal agencies. The first edition (U.S. Army Corps of Engineers, Wetlands Research Program, 1992) presents information provided by the Corps, the EPA, the Soil Conservation Service (renamed Natural Resources Conservation Service in October 1994), the Forest Service, the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, the Bureau of Reclamation, and the U.S. Geological Survey. The Corps surveyed over 25 agencies in 1993. To complement the Corps' reference source, the U.S. Fish and Wildlife Service is maintaining the Wetland Creation/Restoration data base to provide a current compilation of the published literature. A hard copy of the bibliographic material contained in the digital data base also has been produced (Schneller-McDonald and others, 1989).

Federal agencies' research into wetland restoration and creation generally falls into two categories—design implementation and performance evaluation. Major contributions on project design have been made by agencies involved in large-scale development, like the Corps (Maynord and others, 1992) and the Federal Highway Administration (Marble, 1990). The EPA has focused its research on evaluation to support the agency responsibilities under Section 404 of the Clean Water Act (Zedler and Kentula, 1986; Leibowitz and others, 1992). Agencies responsible for stewardship of living resources, such as the National Marine Fisheries Service, have produced information that will increase their effectiveness in management (Thayer, 1992).

The Natural Resources Conservation Service and the U.S. Fish and Wildlife Service probably will contribute the most information on practical, low-cost approaches to wetland restoration under the 1990 Farm Bill (Food, Agriculture Conservation and Trade Act of 1990—(P.L. 101–624) and the Wetland Reserve Program. Under these programs, thousands of wetland acres previously converted to agriculture have been restored to wetlands. To support these efforts, both agencies have produced guidelines for their field personnel who are working with the farmers to restore wetlands (U.S. Soil Conservation Service, 1992; Wenzel, 1992). (For more information on legislation affecting wetlands, see the article "Wetland Protection Legislation" in this volume.)

CONCLUSIONS

Wetland restoration and creation is more an art than a science, and functional replacement of wetlands has not been conclusively demonstrated. At the same time, the growing body of literature and experience is increasing the ability to discern which projects have a high probability of restoring or replacing damaged or lost ecosystems. Two factors that most limit the effective use of restoration and creation are: (1) lack of information on ecologically mature restored and created wetlands, and on the maturation process; and (2) the limited number of well designed and well constructed project wetlands that can be used as models.

In general, restoration is likely to be more successful than creation. Restoration of a damaged or destroyed wetland will have a greater chance of establishing the range of prior wetland functions, including critical habitat. Also, chances are greater for the long-term persistence of a restored wetland than for one created where none existed before.

Figure 56. This pond with a fringe of marsh in Portland, Oreg., is a restored wetland and is an example of the type of freshwater project wetland most common in this country. *(Photograph courtesy of the EPA Wetlands Research Program.)*

Ecosystems that are least likely to be successfully replaced are bogs and fens.

Restoration is likely to be more successful than creation.

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