Wetland Restoration and Creation

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Wetland restoration has been variously defined, but it is most often considered the process, or the result, of returning either a former wetland (now a nonwetland) to a functioning wetland of some type or a degraded, contaminated, or functionally impaired wetland to its prealtered condition. A restored wetland in the former case may or may not be similar to the "original" wetland type, but the net result is an increase or gain in wetland acreage. The other type of restoration seeks to reconstruct the wetland type that existed prior to disturbance, with no net increase in wetland acreage. This latter process may be better termed wetland rehabilitation, where a damaged system is restored to normal. Rehabilitation could include eradication of exotic and/or pest species. Wetland restoration does not include changing the condition of an existing unaltered wetland to improve or strengthen one or more functions. This action is called wetland enhancement and it usually changes the wetland type for the benefit of a particular function, e.g., converting a wet meadow to a marsh–pond complex to improve waterfowl habitat. With more than half of the wetlands in the coterminous United States destroyed, largely through agricultural conversion and hydrologic alteration, there are many opportunities for wetland restoration in the lower 48 states. Wetland creation is the process of constructing a wetland in an upland (nonwetland) area. To build a wetland where one never existed requires creating hydrologic conditions that promote the establishment and successful reproduction of hydrophytes, the development of hydric soils, and the performance of desired wetland functions (e.g., flood storage, shoreline stabilization, pollution abatement, and wetland wildlife habitat). In some cases, wetlands have been unintentionally created by seepage from impoundments, elevated local water tables from irrigation projects, restricted drainage from undersized culverts or lack of sufficient culverts along roads, or other altered drainage patterns that make a site wetter than it was prior to the activity.

I. INTRODUCTION

Wetlands are permanently flooded shallow water areas or periodically flooded or saturated lands. They range from margins of lakes and ponds and lands flooded by the tides to areas that are seasonally saturated for extended periods near the soil surface in most years. Common types include salt marshes, mangrove swamps, tidal flats, inland marshes, wet meadows, prairie potholes, playas, fens, shrub swamps, bogs, pocosins, wooded swamps, certain bottomland hardwood forests, muskegs, and shallow ponds. Wetlands are now considered among the world's most valuable natural resources, providing a wealth of benefits to society, essentially free of charge. These values include fish and shellfish production, wildlife habitat for valued species, temporary flood water storage, shoreline stabilization, water quality renovation, and water-based recreational opportunities. Despite these and other valuable functions, wetlands have been viewed by many cultures as wastelands whose highest purpose could only be attained through conversion to other uses, such as filling for commercial and residential real estate and drainage for cropland or silviculture. As a result of this attitude, many wetlands have been destroyed or significantly degraded in the United States and elsewhere. In the coterminous United States alone, over half of the wetlands that existed prior to European colonization have disappeared. Most of these lost wetlands were either converted to agricultural land (Fig. 1) or destroyed through hydrologic alteration (e.g., channelization/drainage projects and regulated river flows), while filling and dredging were major causes of coastal wetland destruction. [*See* WETLANDS ECOLOGY.]

Public opinion in the United States toward wetlands began changing in the 1960s and 1970s, due largely to scientific reports of wetland functions and values and of increasing losses and threats to natural wetlands. This led some states to enact laws to protect coastal wetlands and later, inland wetlands to varying degrees. The federal government also strengthened its role in wetland protection through the Clean Water Act. These laws and corresponding regulations usually require that persons seeking to alter wetlands first obtain permission or a permit from the applicable regulatory agency (e.g., Corps of Engineers or state wetland agency) prior to commencing work. This gives the government an opportunity to consider and evaluate the potential environmental impact of the proposed work, with the intent of avoiding or minimizing wetland loss or degradation. In obtaining a permit, the permittee may be required to restore or create wetlands to lessen the environmental impact of the project. This compensatory requirement is usually the last step in a sequential impact minimization

FIGURE I Millions of acres of former wetlands have been converted to cropland like this former bottomland hardwood swamp in the lower Mississippi river valley. In many cases, government-sponsored flood control/channelization projects have accelerated such conversions.

process called "mitigation." Ideally, an alternatives analysis should initially be performed to establish that the purpose of a project can only be met by altering the wetland at the proposed site. Then, the impact of the project on wetlands at the site should be minimized to the extent necessary to reasonably satisfy the project's intended goal. Finally, unavoidable wetland losses resulting from project construction should be compensated for by wetland restoration, creation, or other measures. Thus, regulations developed in accordance with various environmental laws serve as a major catalyst for wetland restoration and creation.

II. WHY RESTORE AND CREATE WETLANDS?

Wetland restoration and creation projects offer opportunities to maintain and improve the status of wetlands and their functions. These efforts may, in some way, help offset the cumulative functional losses resulting from past wetland alterations. The major reasons for wetland restoration and creation are (1) to compensate for the impact of proposed wetland alteration permitted through the regulatory process, (2) to repair damaged systems, and (3) to increase wetland acreage above current levels for the purpose of gaining wetland functions that benefit society. The U.S. federal government and some states have adopted an environmental policy of "no net loss" of wetlands. Wetland restoration and creation are vital to achieving this goal, since it is clear that certain wetland alterations will continue to be permitted through government wetland regulatory programs. These programs are designed, in part, to minimize adverse impacts on wetland resources from new development. Consequently, government agencies, industry, landowners, and developers seeking permits to modify wetlands for various projects are often required to mitigate for unavoidable wetland losses as part of the conditions for receiving a government permit. Many of these permitted activities involve both wetland restoration and creation as mitigation for altered wetlands. Other government programs dedicated to encouraging wetland restoration on private property through positive incentives include the U.S. Fish and Wildlife Service's Partners for Wildlife Program, U.S. Department of Agriculture's Conservation and Wetland Reserve Programs, and state-run programs. State and federal wildlife management agencies have been active in wetland enhancement and perhaps, to a lesser degree, in wetland restoration and creation for at least 50 years. They have diked and impounded wetlands and created ponds on public lands for the benefit of certain wildlife, mainly waterfowl. Enhancement projects typically promote one wetland function, while diminishing some other functions.

Nongovernment organizations and private organizations like Ducks Unlimited have been involved in similar projects to improve waterfowl habitat, for example. Wetlands have been touted as natural water quality filters, so artificial wetlands are now being built for municipal, industrial, and agricultural wastewater treatment in North America and Europe. These wetlands are used mainly to polish secondary effluent and for tertiary treatment and stormwater management. Some wetlands are being constructed to control nonpoint source pollution from agricultural lands. In mining regions of the Appalachians in the eastern United States, wetlands have been created to neutralize acidic water runoff from coal mines. In Asia, wetlands have been created to produce the staple, rice, that feeds millions of the world's population. To a lesser degree, private individuals have created wetlands largely to protect their property from shoreline erosion or have restored wetlands for wildlife habitat due to their personal interest in wetland wildlife conservation. Ponds are perhaps the most common and widespread wetland type that private landowners construct without government incentives, although the government has programs to provide partial funding or technical assistance for farm ponds and catfish ponds. This happens chiefly because the value of a pond directly benefits the landowner. One can fish, hunt, obtain water, engage in water-based recreation, or simple enjoy the sight and sounds of pond life, whereas the benefits of many vegetated wetlands are often less tangible. Coastal wetlands and streamside wetlands have been created by private landowners because they derive a direct benefit—protection of property through shoreline stabilization and erosion control—from these wetlands.

III. WETLAND RESTORATION AND CREATION VS PROTECTION

Wetlands form on the landscape where there is frequently an excess of water for prolonged periods. Many wetlands are associated with floodplains of major rivers, low-lying plains along coastal waters, and depressions surrounded by upland where surface water collects. Yet all wetlands do not fit this pattern. Some wetlands have been established on terrains with varying slopes in areas of groundwater discharge. These sites include springs, seeps, and drainage ways. Since wetlands naturally occur in landscape positions where water accumulates or periodically overflows, protection of these naturally occurring wetlands should be favored over wetland restoration and creation. Existing wetlands are performing wetland functions and it is far easier to preserve wetland functions and perhaps to enhance these functions than to create wetlands where they never existed or, to a lesser extent, to restore lost wetlands. This, in essence, is the foundation for the government's sequencing steps for mitigating wetland impacts of proposed projects. If wetland losses can be avoided, they should be. If not, then wetland losses should be minimized and compensated for through wetland restoration, creation, and enhancement. These efforts, however, should not be used as a substitute for protecting naturally functioning wetlands.

If establishment of new wetlands or additional wetland acreage is the objective, then the choice is between wetland restoration and creation. Wetland restoration is usually more likely to successfully establish wetlands than wetland creation because (1) the affected area is a former wetland, (2) it is naturally in the right landscape position in the watershed to accumulate water, (3) it has a seedbank for hydrophyte reestablishment, (4) it possesses drained hydric soils, and (5) it has a modified hydrology that may be restored to its original wetland hydrology. In contrast, wetland creation requires establishing wetland hydrology in an area that did not support wetland. Creating wetland hydrology sufficient to make a wetland is usually a much more difficult task than restoring wetland hydrology. Evaluations of created wetlands built to replace natural wetlands suggest a low success rate, while the potential for success by restoration efforts is much higher. There also remains much question whether created wetlands are functionally equivalent or similar to the natural wetlands they are intended to replace.

IV. DEFINING PROJECT GOALS AND OBJECTIVES

The primary goal of any restoration or creation project should be to establish an area that provides wetland functions—a wetland. Wetlands restored in response to government regulatory requirements are usually intended to provide multiple functions like natural wetlands. Other restored wetlands often have a single purpose, with increasing waterfowl habitat being perhaps the most common and widespread goal in North America. Ideally, the restored wetland should have a self-sustaining hydrology that requires little or no maintenance. However, in practice, there may be considerable operation and maintenance associated with restored wetlands, especially if water levels must be managed to maximize waterfowl use. Created wetlands may be built to replace lost functions of natural wetlands destroyed by various developments or may be designed to perform a special function that society wants, such as wastewater treatment, stormwater management, or erosion control. In the former case, the objective should also be to establish a self-sustaining wetland like a restored wetland with multiple purposes, while the management objectives in the latter typically involve the installation of water control structures, requiring considerable operational and maintenance costs to achieve the desired function.

Without clearly stated objectives, it is virtually impossible to evaluate the success of wetland restoration and creation projects. The lack of specified objectives of many restoration projects has often led critics to claim that these projects are no more than pond creation or wetland enhancement. Ideally, every restoration or creation project should have a written plan detailing the specific goals and objectives and a set of measurable parameters to evaluate project success. This is especially needed for mitigation projects and government-sponsored projects that are designed to replace lost wetland functions. Information from such plans is vital to better understanding why a particular project succeeded or failed and to allow others to reproduce successful results. Documentation for most past projects is either poor or nonexistent, providing little specific guidance on successful methods and problems to be avoided for future projects.

The first and perhaps most important question in any restoration or creation project is what type of wetland is desired? The answer may be easy to determine if the restoration/creation project is being performed to replace functions of lost wetlands; in-kind replacement is the norm. If the desired wetland type differs from the one destroyed (out-of-kind replacement), there must be a good reason for this. Perhaps the intent is to restore wetlands that have been subject to heavy historical losses or to establish wetlands with a particularly high value for one or more functions (e.g., waterfowl habitat, endangered species habitat, or flood storage). The former requires knowledge of wetland status and trends. The U.S. Fish and Wildlife Service has published national statistics on wetland trends and also has similar data available for some specific geographic areas. This information is vital to knowing what wetlands are in greatest need of restoration. Government agencies may choose to restore entire ecosystems, such as the Kissimmee River and the Everglades of Florida or the bottomland hardwood swamps of the lower Mississippi alluvial plain, or may opt to restore individual wetlands in high priority watersheds or regions, such as prairie potholes in the upper Midwest. In some cases, wetlands may simply be restored or created where there is a willing participant, but this is probably the least desirable option from an ecosystem management standpoint. Restoring a wetland requires knowledge of its condition prior to alteration. For recent disturbances, this may be accomplished through conventional photointerpretation techniques. Aerial photos predating the perturbation may be examined to determine the previous wetland type. Such photography is available for many areas back into the late 1930s and early 1940s.

After deciding what type of wetland to restore or create, a number of questions arise. The 10 questions listed here are examples of questions that will aid in site selection and project design.

1. What government regulations may apply to construction activities required by the restoration/creation project? (Federal Clean Water Act, state wetland laws, local zoning bylaws, etc.)
2. Where are the lands suitable for restoration or creation and are they available for the project? (Former wetland sites, uplands with high water tables, existing land use, land ownership, water rights, etc.)
3. Given the above, should the project be a wetland restoration or a wetland creation?
4. What should the project size be?
5. If the project is being initiated in response to a government permit for wetland alteration, should the restoration/creation be located on-site, off-site in watershed, or off-site out of watershed?
6. What hydrologic conditions are to be established? (Water depth, flooding frequency and duration, seasonal water tables, tidal flow regime, etc.)
7. What plant communities are desired? (Dominant species, diversity, ratio of vegetation to open water, etc.)
8. How much time should be allowed for wetland vegetation to establish?
9. What faunal species and kind of animal use are desired? (Feeding, nesting, brood rearing, wildlife travel corridors, etc.)
10. What is an acceptable risk of structural failure (such as washed out culverts or eroded berms) that would require repair at some frequency (e.g., 5, 10, 25, 50, or 100 years)?

The answers to these questions will likely vary depending on whether the objective is to establish a naturally functioning wetland or to restore or create a wetland for a specific purpose.

Several sources of existing information are available to help answer some of the preceding questions. These sources include National Wetlands Inventory (NWI) maps (U.S. Fish and Wildlife Service), soil survey reports (U.S.D.A. Soil Conservation Service), state water summaries (U.S. Geological Survey), climate data (U.S. Weather Bureau), and state or local wetland maps. By comparing NWI maps with a soil survey report, for example, potential sites for restoration may be detected (i.e., hydric soil map units without NWI wetlands). Soil survey reports may also be used to find upland sites with high potential for wetland creation. Field inspections are required for evaluating the actual site potential for wetland restoration or creation. These sources provide useful background information to aid in identifying potential sites.

V. PROJECT DESIGN

Successful designs for restoration and creation projects require assessment of both on-site and off-site environmental conditions and application of current knowledge of wetland formation processes and wetland functions. In restoring or creating wetlands, site selection is the first step toward project success. If the project is being initiated in response to a regulatory requirement, the regulatory agency will usually provide guidance on the on-site/off-site and the wetland restoration vs creation questions. Sites best suited for restoration are hydrologically modified former wetlands where wetland hydrology is easy to reestablish (Fig. 2). Such sites possess drained hydric soils and contain a natural seedbank of hydrophytic species that should greatly improve the chances for successful revegetation. For constructed wetlands, site selection is most critical, especially if attempting to create a wetland that is somewhat functionally equivalent to the one destroyed. The location should be one where wetland hydrologic conditions can be efficiently and effectively replicated. The best sites probably are adjacent to existing wetlands or water bodies where lowering the ground surface through excavation will expose the affected area to wetland hydrologic conditions. The hydrology of these created wetlands may be surface water- and/or groundwater-driven or artificially controlled. Similarly, wetland basins may be created by excavating an isolated depression to a point at or below the local groundwater table. This is how many ponds are built. These artificial wetlands are essentially groundwater-driven systems, although contributions of surface water through runoff are variable, depending on the size of the upstream watershed. Other ponds and wetlands may be created by impounding a natural valley to collect surface water. For any surface water-driven wetland, the quantity and quality of the inflowing water are of utmost importance. Too much suspended sediment can accelerate basin filling and affect plant composition, wetland hydrology, and associated wetland functions. Contaminated waters could produce disastrous consequences for certain wetland functions, especially fish and wildlife habitat. Wetlands may also be created within water bodies by depositing fill material and stabilizing this material with wetland plants and/or man-made erosion control fabrics. This is frequently done in creating coastal marshes on dredged material disposal sites and to stabilize eroding shorelines along freshwater rivers, lakes, and streams. In addition to hydrology (water quantity and seasonal fluctuations in water levels) and other water-related properties (e.g., water chemistry), other features to consider in site selection include local topography, soil properties (e.g., texture, permeability, fertility, erodibility, and underlying substrates), degree of site exposure to wave action (for sites in large water bodies), the ratio of the acreage of wetlands/water bodies in the watershed to the total watershed acreage, predominant land use in the watershed, and land use adjacent to the site.

Once a site is selected, a number of other environmental parameters should be evaluated, including channel slope or gradient, ground elevations at the site (through topographic surveys), the proximity to other wetlands, and the presence of populations of exotic and/or potential pest plant species. These and other factors (e.g., culvert sizes above and below the project site) will provide valuable information for (1) establishing the scope and effect of the project (e.g., size and shape of wetland and planned hydrology), (2) determining externalities

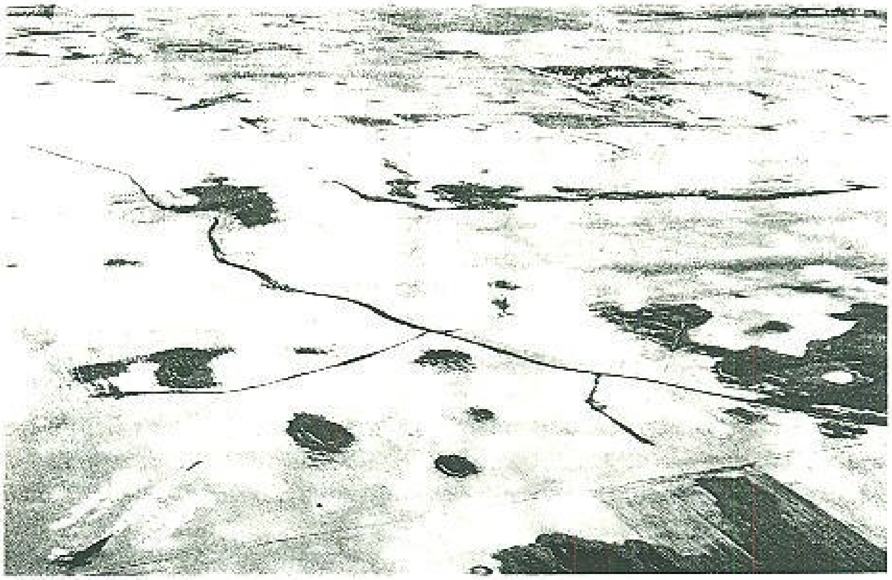

FIGURE 2 Former wetlands drained by open ditches are among the easiest wetlands to restore. Many areas similar to the one shown in North Dakota are suitable for marsh and wet meadow (prairie pothole) restoration. The federal government is actively engaged in wetland restoration in this area.

that may affect project success (e.g., storm flows), (3) developing contingency plans to get rid of excess water and for drawdown, and (4) evaluating potential impacts to adjacent properties and downstream areas.

Knowledge of wetland formation processes and wetland functions provides the basis for determining the critical elements to restore or construct wetlands. All wetlands are not functionally equivalent. Some wetlands have higher capacities to perform certain functions than others. Consequently, the functional analysis of wetlands proposed for alteration provides the foundation for determining what mitigation should be required in regulatory cases. Functional evaluations of neighboring wetlands can also provide useful information for project design, especially when the project is not the result of a regulatory action. Specific designs can be drafted to accentuate specific functions, if desirable. Some points to consider in designing wetland restoration and creation projects include: (1) ratio of open water habitat to vegetated wetland, (2) wetland type and desired plant community composition, (3) method of revegetation (e.g., natural recruitment of plants, dressing topsoil with hydric soil containing natural seedbank, or seeding/planting), (4) sources of planting stock (e.g., transplanted local stocks, nursery-grown native plants, or horticultural varieties), (6) planting time, (7) soil fertility and organic matter composition, and (8) desired hydrology (e.g., frequency and duration, sheet flow, channelized flow, and amount of water management).

Documentation of vital site characteristics and functional design specifications will greatly help in evaluating project success and in replicating successful results for other areas. It must be remembered, however, that excellent project design also requires proper implementation to achieve success. Designed elevations may be perfect, but if site preparation fails to attain these levels, then the project may be doomed. In wetlands, for example, small changes in elevation can make an enormous difference in the environmental conditions that greatly affect plant establishment, survival, and reproduction.

VI. WETLAND RESTORATION AND CREATION TECHNIQUES

Establishing the appropriate hydrologic regime is critical for all wetland restoration/creation projects. Hydrology is the driving force that creates, maintains, and largely determines functions for wetlands in nature. Replicating wetland hydrology is vital to the success of any project. This is mainly accomplished by three methods: (1) controlling ground surface elevations (chiefly for creation and restoration of filled wetlands; Figure 3), (2) regulating the water depths and duration through a combination of earthen dikes and water control devices (for restoration, enhancement, and creation), and (3) destroying existing drainage structures (mainly for restoration). The first is done by excavating soil to a level where permanent or periodic flooding or prolonged soil saturation will occur. The second action involves installation of water control devices (e.g., gates, valves, riserboards, or stoplogs) to attain desired water levels in the diked area (impoundment). The final method requires plugging drainage ditches or breaking tiles to effectively demolish the current drainage system and restore wetland hydrology. Achieving and maintaining the desired hydrology are probably the greatest obstacles facing restoration and creation efforts. Unpredicted low water tables, extremes in climatic conditions (e.g., droughts and floods), improper site grading and slopes, coarse-textured soils, and erosion contribute to this problem.

After planning the desired hydrology, attention usually focuses on establishing a wetland plant community of a particular type. Species composition, maintenance of genetic diversity of local wetland ecotype stocks, seed/seedling sources (including salvage plants from wetlands planned for alteration and hydric soils with natural seedbanks from donor wetlands), plant material handling, planting techniques, spacing requirements, planting/seeding times, fertilization, substrate/soil type, plant survival and reproduction, and control of exotic and pest species are among the major issues facing wetland restoration and creation projects. Herbivory by insects, geese, muskrats, and rabbits, for example, is also a potentially significant issue that must be dealt with by some projects.

Techniques for restoring and creating wetlands often vary with the desired wetland type due to plant species requirements and different environmental conditions. Aquatic beds, estuarine wetlands (salt/brackish marshes and mangrove swamps), and palustrine wetlands (inland marshes, swamps, and bogs) all have somewhat unique circumstances to deal with. The following paragraphs of this section address some of these differences. Pond creation will not be discussed, but it should be recognized that ponds have been successfully created by many cultures throughout the course of human history.

Efforts to restore aquatic bed vegetation require establishing plant communities in permanent shallow water. Critical environmental factors for site selection, besides water depth and substrate, may include turbidity, sedimentation, thermal pollution, and oil/chemical pollutants. Many projects in large water bodies, especially estuaries, major rivers, and large lakes, must address the effects of water currents and wave action. Low-energy sites are best suited for the establishment of aquatic beds. Much restoration has been performed in estuaries. Typical species involved in these projects are eel grass (*Zostera marina*) and widgeon-grass (*Ruppia maritima*) in northern U.S. estuarine waters and turtle-grass (*Thalassia testudinum*), manatee-grass (*Cymodocea filiformis*), shoal-grass (*Halodule wrightii*), and sea-grasses (*Halophila* spp.) in southern waters. Although seeds may be planted directly into the substrate, the planting of individual specimens or plugs is more typical. Most plants are collected from local populations to maintain genetic diversity and fitness for local environmental conditions. Plantings may be anchored in some fashion (e.g., steel staples or biodegradable meshes) to prevent washouts. In general, the best sites for restoration are former sites where water quality has improved or elevations are now suitable for reestablishment. In freshwater systems, target species for restored or created aquatic beds include white water lily (*Nymphaea odorata*), spatterdock (*Nuphar* spp.), and pondweeds (*Potamogeton* spp.). At created sites, flooding is required after seed germination or transplanting. If planting needs to be stabilized to preventing uprooting, biodegradable meshes may be used.

Restoration of estuarine marshes is limited since most of the historic losses were due to dredging and/or filling which eliminated these habitats. It is

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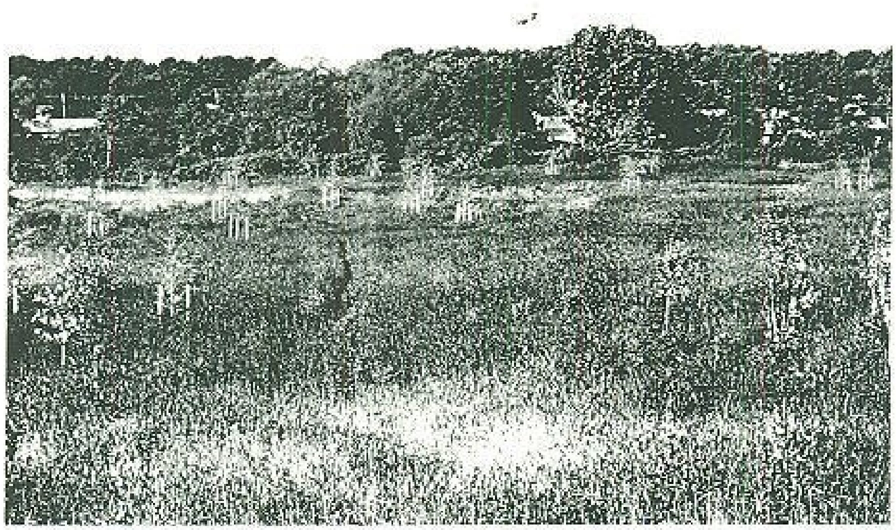

FIGURE 3 Wetland restoration and creation may require soil removal to the seasonal high water table to restore or create wetland hydrology. (A) Grading of a project site nears completion in June. (B) Site just 3 months later, after seeding and planting over 1500 shrubs. While the results look impressive, this project will require monitoring over several years to determine whether the project has achieved its objectives. (Photos courtesy of Fugro-East, Northborough, MA.)

not likely that dredged material will be returned to the created canals or channels or fill material removed from affected areas since most are occupied by buildings of various kinds. If, however, fill is recent and the activity was unauthorized, government regulators usually require the responsible individual to remove the fill and restore the affected wetland. Perhaps the greatest opportunities for restoration of estuarine wetlands are on dredged material disposal sites where former marshes were filled. Yet the costs for removing this material may be prohibitive given current technologies. Many coastal marshes have been impounded, yet most are managed as estuarine systems and could be returned to more naturally functioning wetlands, if desired. Other wetlands have restricted tidal flows that have reduced salinities creating brackish conditions, thereby allowing common reed (*Phragmites australis*), narrow-leaved cattail (*Typha angustifolia*), and other plants to invade and dominate many former salt marshes. This condition is easily remedied by enlarging culverts, breaching dikes, or through other means. Smooth cordgrass (*Spartina alterniflora*) returns quickly to these sites, provided that the subsidence of marsh soils has not been significant. These impounded and degraded marshes are suitable for rehabilitation which is often considered a form of restoration. Significant opportunities also exist for estuarine wetland creation to stabilize dredged material deposited in shallow water and tidal flats or to protect eroding shorelines from wave action. Some coastal states, including Maryland and Delaware, have actively encouraged private property owners to build estuarine wetlands to stabilize shorelines (Fig. 4) instead of constructing bulkheads and rip-rap structures for erosion control. Wetlands may be created through the excavation of uplands adjacent to estuarine marshes, with material removed to a level that promotes frequent tidal flooding. All these projects have little problem accessing hydrology since they are established along tidal embayments, rivers, or existing estuarine marshes. The main obstacles are attaining proper elevations, planting the various species at the right levels, and reducing the effects of wave action. Other important factors in project success are salinity, soil properties, site drainage characteristics, proper acclimation of nursery-grown stock prior to transplanting, nutrient availability (especially nitrogen), and controlling herbivory and human actions (e.g., foot traffic and ATVs). Snow geese and muskrats have caused major problems for some creation projects. Suitable species for estuarine marsh restoration and creation are halophytes (salt-tolerant plants), including smooth cordgrass for regularly flooded (low marsh) sites and salt-hay grass (*S. patens*), big cordgrass (*S. cynosuroides*), salt grass (*Distichlis spicata*), and black needlerush (*Juncus roemerianus*) for irregularly flooded (high marsh) sites on the U.S. Atlantic and Gulf coasts. On the U.S. West Coast, Pacific cordgrass (*S. foliosa*) is the major species planted. Direct seeding has been done. Alternatively, sprigs, seedlings, and plugs have been hand planted or mechanically planted.

Mangroves dominate the coastlines of the world's tropics. Mangroves have been planted for silviculture in the Philipines for about 200 years. Red mangrove (*Rhizophora mangle*) is the most widely planted species in Florida, whereas black mangrove (*Avicennia germinans*) and white mangrove (*Laguncularia racemosa*) have also been planted. Mature seedlings (propagules) are collected from local swamps. These propagules may be directly planted or planted aerially. In some cases, individual shrubs or trees may be planted, but this increases project costs. The best sites for restoration/creation are low-energy shorelines, sheltered from strong wave and current action. Attempts to establish mangroves in high-energy environments have a low potential for success. High salinities and elevated soil surface temperatures pose serious problems at some sites.

Inland marshes are among the easiest wetlands to restore and create and are probably the most widely established wetland type in the United States. Marshes represent early stages in hydrarch succession and are generally resilient and tolerant of disturbance. Prairie pothole marshes, for example, are well-adapted to drastic annual fluctuations in water levels and their high productivity is directly related to these dynamics. Since many of the former marshes were drained and converted to cropland, it may be relatively simple to restore wetland hydrology and, thereby, reestablish these wetlands. The soils contain a natural seedbank or reservoir of hydrophytic plants species, so once wetland hydrologic conditions return, these plants quickly recolonize the site. The buried seeds of hydrophytes may remain viable for centuries. Perhaps the easiest marshes to restore are small, isolated former wetland basins that have been drained by open ditches

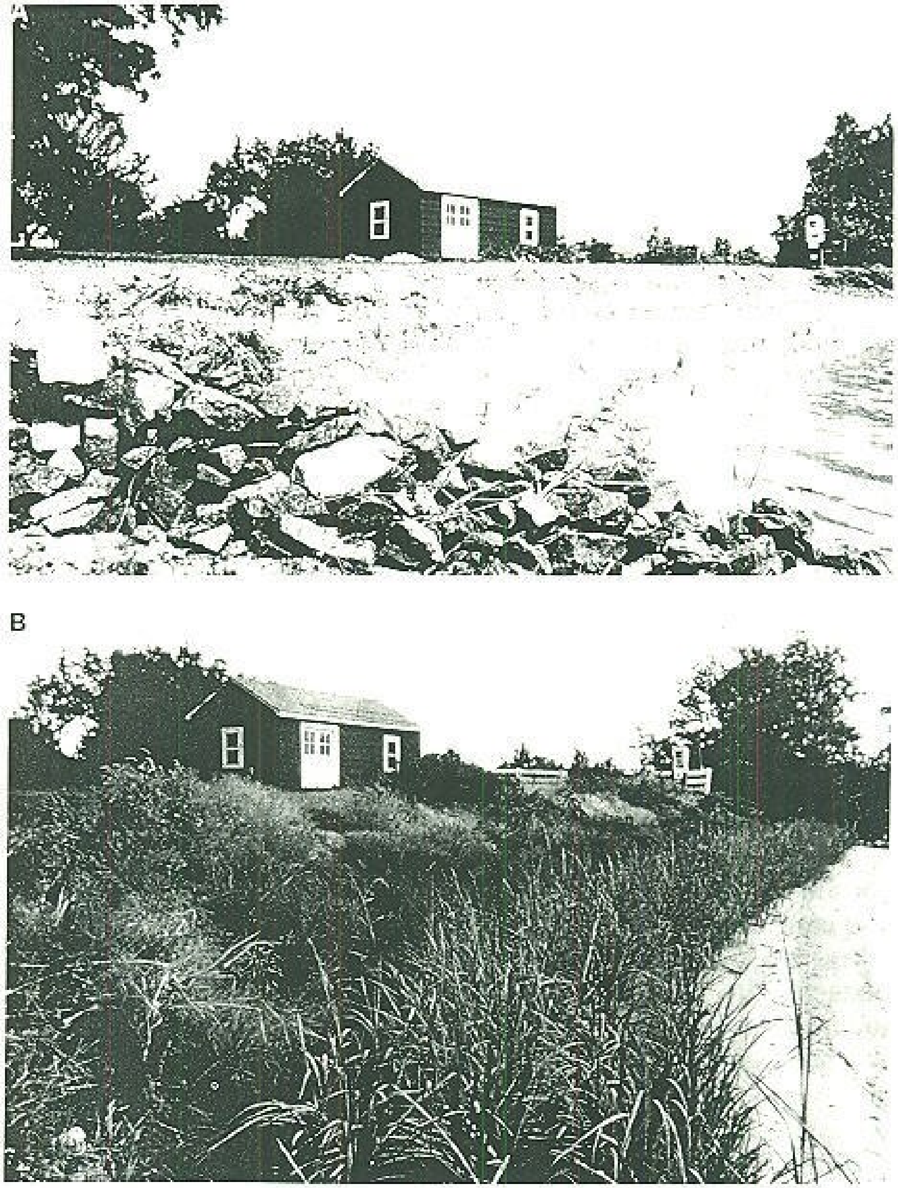

FIGURE 4 Estuarine wetlands are being created along eroding shorelines in coastal waters. These projects involve planting halophytic species like smooth cordgrass (*Spartina alterniflora*) which usually form dense stands within 1 year. (A) A created marsh soon after planting, (B) the same area 1 year later.

(Fig. 2). Cleaning out the organic matter in the ditch and then placing an earthen plug in the ditch can bring back wetland hydrology. Basins with larger watersheds require culverts and/or spillways, plus erosion control measures (e.g., biodegradable meshes, rip-rap, and anti-seepage diaphragms) to prevent washouts. Former wetlands that are tile drained are more difficult and costly to restore. First, one has to locate the tiles, then destroy a portion of the tile system, and install a ditch plug with a spillway. It is probably advisable to till or disk restoration sites prior to restoring wetland hydrology, so that existing turf is broken down and thereby facilitating colonization by seedbank hydrophytes. Failure to do this may significantly slow revegetation. Many marsh restoration projects are actually wetland enhancements where the hydrology of an existing wetland, usually a wet meadow, is changed to that of a marsh by increasing the hydroperiod through a combination of dikes and water control structures. Marsh creation requires additional considerations. One must create a wetland basin in an upland site by excavation (Fig. 3) and/or impoundment of a natural valley. Ideally, if hydric soil (with its natural seedbank) can be brought from the altered site to the creation site, it may be easier to establish the desired plant community than by plantings or seeding. For all projects, first-year water levels are critical. With few exceptions, marsh plants tend to germinate best in moist to saturated soils. The seedlings of most species are very susceptible to early season flooding, so it is usually recommended that the site's initial hydrology be one of saturated soils (until seedlings attain some height) followed by shallow flooding (less than 1 inch of water). It is important not to inundate the entire plant during the first year. In future years, flooding depths can be gradually increased to reach the desired level. All projects should have contingency watering plans, especially for projects in arid and semiarid regions, to ensure favorable conditions for plant growth during the critical first year. Shallow wells may be installed if necessary. Marsh restoration and creation projects should consider producing a diversity of habitats, including islands and other wetland types. The hydrology required for the establishment of wet meadows is one of alternating prolonged periods of saturated soils with brief shallow flooding events. Because grazing may pose a problem for some meadows, exclusion fences may be required. Common plant species in freshwater marshes and meadows that have been used in restoration and creation include cattails (*Typha* spp.), bulrushes (*Scirpus* spp.), pickerelweed (*Pontederia cordata*), arrowheads (*Sagittaria* spp.), arrow arum (*Peltandra virginica*), sedges (*Carex* spp., *Eleocharis* spp., *Cyperus* spp.), reed canary grass (*Phalaris arundinacea*), and panic-grasses (*Panicum* spp.). Wetlands constructed for wastewater treatment in the United States and Europe have used the following species which have recognized values for nutrient uptake (nitrogen removal) and assimilation suitable for this treatment: broad-leaved cattail (*T. latifolia*), soft-stemmed bulrush (*Scirpus validus*), tule or hard-stemmed bulrush (*S. acutus*), bulrush (*S. lacustris*), woolgrass (*S. cyperinus*), common reed (*Phragmites australis*, the principal species used in Europe), reed canary grass, water hyacinth (*Eichhornia crassipes*), and rushes (*Juncus* spp.). Building wetlands for this purpose requires much more elaborate design, operational, and maintenance considerations than creating wetlands for wildlife habitat. This added effort is needed to maximize the plant–soil interaction with wastewater for removing pollutants and microbial pathogens.

Many types of shrub swamps may be as easy to establish as marshes and wet meadows because of similar hydrologies. Site preparation is also similar (Fig. 3). The planting of seedlings is probably the most typical revegetation technique for shrubs, with some exceptions. Willow twig cuttings may be directly planted at restoration sites. Common species that have been used or may be suitable for restoration/creation projects include willows (*Salix* spp.), buttonbush (*Cephalanthus occidentalis*), dogwoods (*Cornus* spp.), alders (*Alnus* spp.), arrowwoods (*Viburnum* spp.), winterberries (*Ilex* spp.), swamp azalea (*Rhododendron viscosum*), sweet pepperbush (*Clethra alnifolia*), and highbush blueberry (*Vaccinium corymbosum*). Varieties and relatives of the latter species are widely cultivated on former wetland sites for berry production in New Jersey. Bogs, however, are a notable exception. Bogs characterized by ericaceous shrubs (e.g., leatherleaf, *Chamaedaphne calyculata*) are perhaps the most difficult wetland type to establish because of their unique soil chemistry and deep organic soils, although there is at least one report of an attempt to relocate a bog. Perhaps the dense shallow root system binds the organic soil and makes it possible to carefully remove a living carpet of bog vegetation, much like sod or turf mats used for establishing residential lawns. If possible, this probably would be a very labor-intensive and costly project. [*See* BOG ECOLOGY.]

Restoration of forested wetlands takes longer to successfully accomplish than for emergent wet-

FIGURE 5 Bottomland hardwood forest restoration in eastern Louisiana. It will take 10 years or more for the forest to develop, so these types of restoration projects require longer monitoring than restored marshes and wet meadows.

lands and most shrub swamps simply because it takes more time for trees to mature and a forest to reestablish. The most extensive forested wetland restoration projects involve bottomland hardwood forests (Fig. 5). Millions of acres of these wetlands have been converted to agriculture (e.g., soybean fields) in the southeastern United States, especially in the lower Mississippi alluvial plain. Consequently, the potential for restoring these forests is enormous. The best sites for restoration are poorly drained or frequently flooded cropland that is considered low value farmland because of excessive wetness and frequent crop failure. Species used in restoration depend on wildlife habitat/forestry objectives. Zonation patterns of bottomland plant communities correspond to elevational gradients and differences in the frequency and duration of flooding. Observing plant distribution in neighboring bottomland swamps provides valuable insight for species selection for proposed restoration sites. Typical southern bottomland species include bald cypress (*Taxodium distichum*), oaks (*Quercus* spp.), pecans (*Carya* spp.), ashes (*Fraxinus* spp.), elms (*Ulmus* spp.), sweet gum (*Liquidambar styraciflua*), black gum (*Nyssa sylvatica*), water hickory (*Carya aquatica*), silver maple (*Acer saccharinum*), and sycamore (*Platanus occidentalis*). Bottomland reforestation involves site preparation (e.g., disking the soil to a foot or more to remove existing vegetation and control rodents, and soil fertilization, if necessary) prior to seeding or planting. Planting seedlings (over 1.5 feet tall) is the typical method, while direct seeding by hand or machines has also been done. Oaks, pecans, and other tree species with large seeds may be planted directly into the soil. Some tree species are suitable for direct planting of fresh twig cuttings, although most are prerooted following standard horticultural techniques prior to planting. These species include poplars (*Populus* spp.), sycamore, ashes, willows, and sweet gum. There are reports of relocating entire swamps where full-sized trees and associated shrubs were replanted at the new site. This practice is extremely limited, probably because of high costs. It is, however, the fastest way to create a forested wetland. Attempts to restore forested wetlands are limited elsewhere, perhaps, in part, because these types have not experienced the tremendous historical losses that their southern counterparts have and because government-sponsored restoration is focusing on other wetland types. Saplings of red maple (*Acer rubrum*) and other

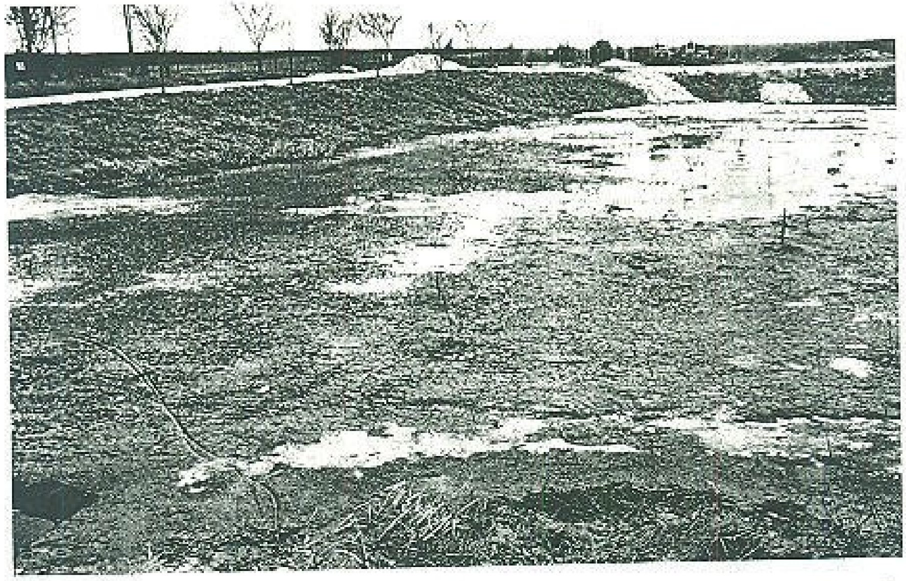

FIGURE 6 This forested wetland project involves both restoration and creation to mitigate for wetland alteration during roadway expansion. The area has been planted with saplings of trees and shrubs typical of palustrine forests in the vicinity. It will take many years for this wetland to function as a forested wetland.

northern species have been planted with shrubs and other plants in red maple swamp restoration/creation projects in the Northeast. These projects are usually required as mitigation for permitted work in natural wetlands (Fig. 6).

VII. MONITORING AND EVALUATION

Due chiefly to the difficulty of establishing the desired hydrology, it is vital that project sites be monitored and evaluated for success. The hydrology of the newly established wetland should be monitored frequently during peak flows to ensure that design is working as planned. During such times, it is advisable to make a few on-site inspections each week. If the design has taken all significant environmental factors into account and the project is constructed exactly as drawn, the project will probably succeed. Practical experiences suggest, however, that it is easier to draft a good plan on paper than it is to build it on the ground. For this reason, it is advisable to record the as-built dimensions of the project after construction. The final dimensions will largely determine the fate of the project.

Most projects that fail, do so mainly because they did not establish the desired hydrology. Besides poor project design, there are numerous other significant problems leading to project failure, including planting at inappropriate elevations, invasion by undesirable species, lack of organic matter in the soil, overcompaction of substrates, grazing by herbivores, vandalism, human traffic, and climatic extremes such as droughts, floods, and hurricanes.

Most problems arise in the first couple of years when the plants are establishing themselves, so it is imperative that all restoration and creation sites be monitored for at least 2 years. Detection of problems during this time will allow necessary adjustments to be made with minimal loss of desired wetland functions. Quarterly observations may be advisable during the first year for all projects. Documentation of observations and remedial actions taken is imperative. Marshes, wet meadows, and shrub swamps (excluding bogs) should probably be evaluated in years 1, 2, and 5 following project completion. Forested wetland restoration projects

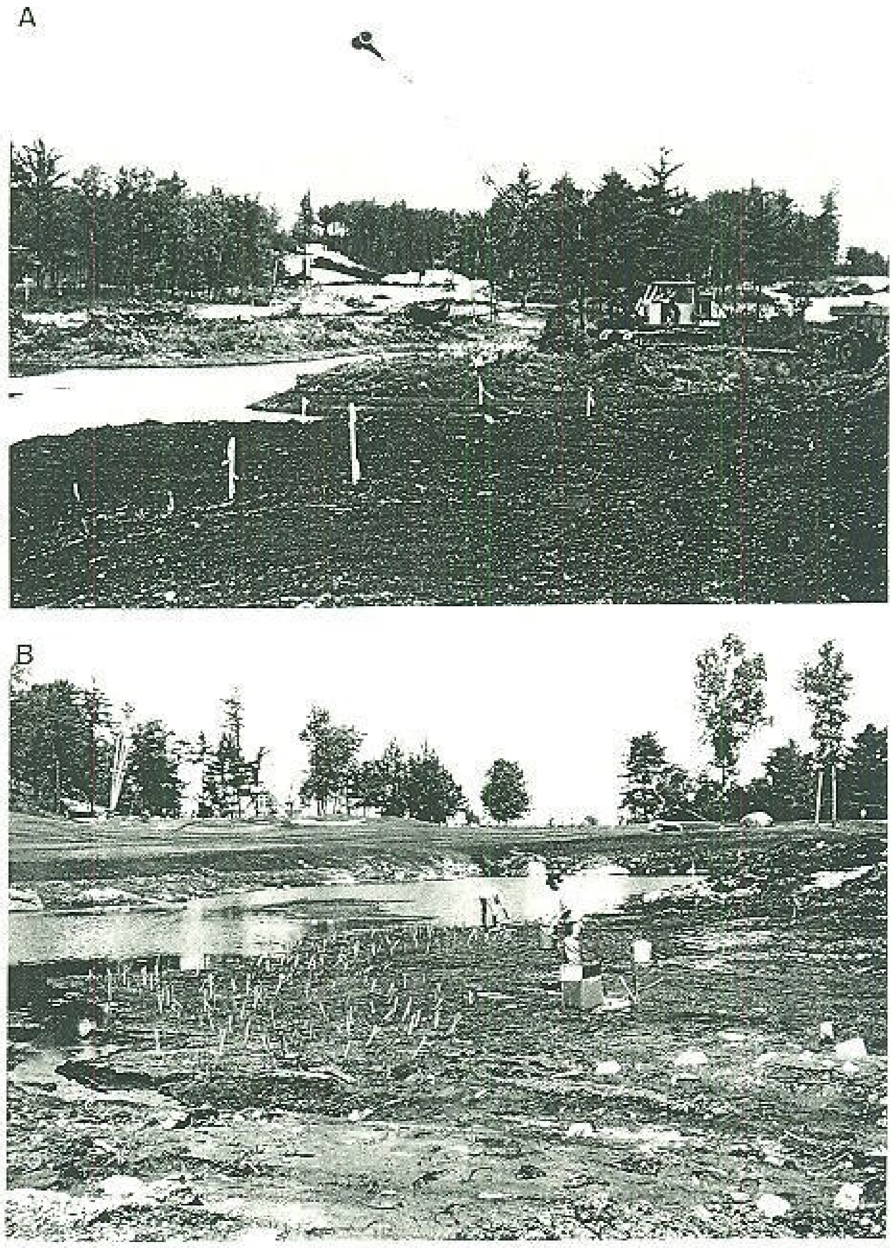

FIGURE 7 Photos are often taken to show the evolution of a wetland restoration or creation project, but they provide little data on project success. To improve their value, photos should be taken from permanent locations. (A) Project during site preparation. (B) Site planting. (C) Restored wetland after 2 years. This project involved planting about 33,000 tubers of marsh herbs and more than 100 shrubs. Eighty percent vegetative cover was attained within two growing seasons. (Photos courtesy of Fugro-East, Northborough, MA.)

C

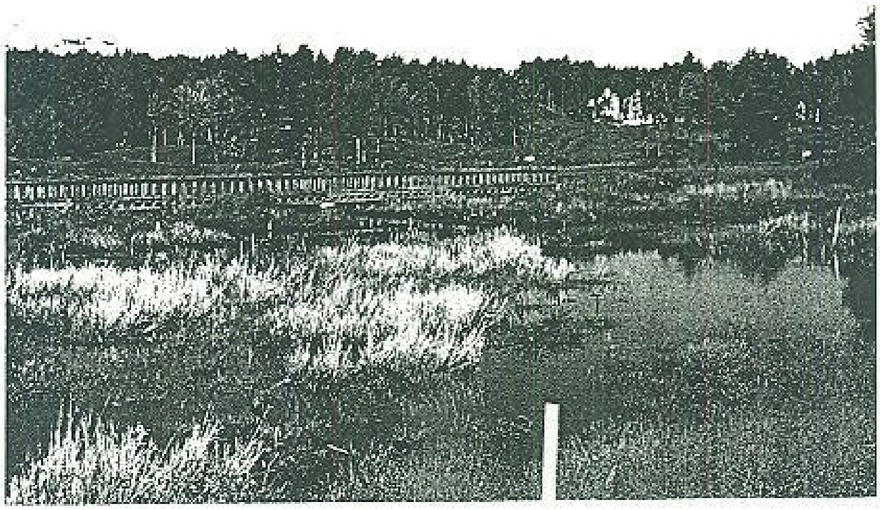

FIGURE 7 *Continued*

should be monitored for longer periods, perhaps 10 years at a minimum, to assess revegetation success. For these wetlands, a monitoring schedule might require site evaluation in years 1, 2, 5, and 10. Fifty years of monitoring is unreasonable as a requirement for government permits, but this length of time may actually be required to fully evaluate the success of restoring bogs and some forested wetlands.

What measures are used to evaluate project success? First, the project's goals and objectives should provide a means for determining appropriate criteria. What are the intended functions to be performed by the restored or created wetland? The answer to this question should be included in the project design plan. Comparisons between restored/created wetlands and natural wetlands of similar form and function are often useful for assessing project success, but do not expect them to be exactly alike. Since it is easier to evaluate form rather than function, most criteria used to evaluate restored or created wetlands are form related. Some commonly used parameters are size and shape of the wetland, type of wetland, interspersion of vegetation and open water, amount of shoreline or edge, water depth and seasonal fluctuations in the water table (surface water and groundwater well monitoring), plant species composition (diversity) at different elevations, plant cover, weighted average of "wetland" species vs "non-wetland" species, stem density, plant height, aboveground and belowground biomass, basal area, seedling survival rates, number of volunteer plant species, reproductive success of plants, wildlife species, wildlife use, wildlife abundance, aquatic invertebrate diversity and biomass (for marshes), accumulation of organic matter in the soil, and water quality (e.g., nitrogen, phosphorus, and suspended solids). Wetlands created or restored for one particular function are evaluated relative to that goal. Panoramic photos are often taken to show the before and after condition of the project site, but they usually provide insufficient information to judge project success (Fig. 7). To be most beneficial, these photos should be taken from permanent locations so that periodic comparisons can be made. Low-altitude aerial photos acquired during the peak of the growing season over a series of years would show the extent and annual changes in vegetative cover and the open water to vegetation ratio at the site.

This could be supplemented with ground surveys to verify species composition and other parameters.

Careful documentation throughout the entire project is critical not only for evaluating project success, but also for being able to reproduce successful results in the future. This provides indispensable information on the do's and don'ts of wetland restoration and creation. Far too many projects have paid little or no attention to this aspect. Given the tremendous acceleration of wetland restoration/creation projects, it is imperative that projects be well-documented from the planning stage through the completion of monitoring. Only by meticulous recording and reporting will we be able to better understand the factors affecting both the successes and failures of wetland restoration and creation and to better design and construct future projects for improving the status of wetlands and increasing the valued functions they perform.

Glossary

Estuarine wetlands Wetlands periodically inundated by salt or brackish tidal waters (salinity above 0.5 parts per thousand), including salt and brackish marshes, mangrove swamps, salt barrens (salinas), and tidal flats.

Halophyte A plant adapted for life in saline soils and characteristic of salt and brackish tidal marshes and mangrove swamps, inland saline marshes and meadows in arid and semiarid regions, and salt flats.

Hydric soil Soil that is saturated, flooded, or ponded long enough during the growing season for anaerobic and reducing conditions to develop in the upper part and that typically supports the growth of hydrophytes; soil characteristic of marshes, swamps, bogs, and other wetlands.

Hydrophyte An individual plant adapted for life in water or in periodically flooded and/or saturated soils (hydric soils) that exhibit prolonged anaerobic conditions; plants growing in deepwater habitats and wetlands; may represent the entire population of a given species (obligate hydrophytes) or only a subset of individuals (e.g., wetland ecotypes) so adapted (facultative-type hydrophytes).

Palustrine wetlands Nontidal wetlands and freshwater tidal wetlands that are typically dominated by persistent vegetation, including marshes, wet meadows, prairie potholes, playas, fens, pocosins, shrub swamps, wooded swamps, certain bottomland hardwood forests, wet flatwoods, Carolina bays, hydric hammocks, muskegs, and wet tundra.

Wetland A vegetated or nonvegetated area that is permanently covered by shallow water (less than 6.6 ft or 2 m) or is periodically inundated and/or saturated near the soil surface by surface or groundwater at a frequency and duration usually sufficient to create prolonged anaerobiosis that favors the growth and reproduction of hydrophytes and the development of hydric soils; includes a diverse assemblage of wet habitats ranging from shallow aquatic habitats to seasonally saturated lands such as marshes, bogs, swamps, fens, prairie potholes, Carolina bays, pocosins, playas, vernal pools, ponds, tidal flats, wet flatwoods, hydric hammocks, and certain floodplain and bottomland forests.

Wetland creation Process or result of constructing a wetland where one did not exist; the process may be either intentional (e.g., to create a wetland for wastewater treatment) or accidental (e.g., seepage from an earthen impoundment), but the net result is a gain in wetland acreage.

Wetland enhancement Process or result of changing the existing condition of a wetland to improve one or more of its functions, with little or no change in wetland acreage; usually changes the wetland type (e.g., wet meadow to marsh).

Wetland rehabilitation Process or result of restoring a degraded, contaminated, functionally impaired, or otherwise damaged wetland to its original (prealtered) condition.

Wetland restoration Process or result of returning a former wetland (now nonwetland) to a functioning wetland of some other type which produces a net gain or increase in wetland acreage; also defined by some authors to include wetland rehabilitation and wetland enhancement activities (see preceding definitions).

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