DECISION SEQUENCE FOR FUNCTIONAL WETLANDS RESTORATION

M. M. DAVIS
US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180 USA

Abstract. As wetland functions are being more clearly evaluated, demand is increasing for the ability to mitigate for specific wetland functions that have been degraded. When wetland restoration project goals specify functions, success of the project depends heavily on proper guidance for project siting, design, implementation, and monitoring. A decision sequence is presented for wetland restoration projects to help achieve functional replacement. This methodology incorporates site selection and design features for specified wetland functions into three phases of a project planning decision sequence. The first phase, site selection, situates a wetland where there is the potential to perform a function. Phases two and three, the incorporation of functional design features into design criteria and project plan development, focus on the optimization of the functional capacity of a site. An example is given of how a wetland restoration project planning team can consider enhancing vegetation diversity during the project plan development phase to achieve a goal of improved wildlife habitat.

1. Introduction

Wetland restoration efforts are become increasingly important as wetlands continue to be degraded throughout the United States. The increase in extent and variety of wetland restoration projects is due to the recognition of the value of wetland functions to society and legislation mandating the protection of wetlands. Wetland restoration, however, is expensive to perform and many projects have not been successful (Kusler and Kentula, 1990). As a result there is a great demand for information about wetland restoration techniques that help achieve project goals and improve restoration success rates as economically as possible. Furthermore, as procedures for assessing wetland functions improve (Brinson, 1993a), demand is increasing for the ability to mitigate for specific wetland functions that have been lost or degraded.

Until recently, wetland restoration project design was based on the assumption that wetland functions followed form. If hydrologic and substrate conditions were established that supported a given type of vegetation, such as emergent herbs or trees, it was assumed that a functioning wetland had been successfully established. However, not all wetlands perform the same functions, nor do all wetlands have the capacity to perform functions to the same level (Adamus *et al.*, 1991, Brinson, 1993b). While limited functions probably were restored, the restored wetland did not necessarily replace the lost functions of the impacted wetland that were being mitigated. The old adage "function follows form" must be more closely examined (Marburger, 1993). Specific functional restoration of future wetland projects will depend on technical guidance for project siting, design, plan development and implementation, and monitoring methods.

Water, Air and Soil Pollution **77**: 497–511, 1994.

Wetland restoration project managers make many decisions at different phases of project development that affect how a wetland will attain functional goals. For example, alternate project sites must be evaluated and selected. Design criteria are specified. A project plan is developed that incorporates the design criteria with the site conditions. The project must be constructed and monitored over time. Information is available for general wetland restoration techniques (e.g., Hammer, 1992, Soil Conservation Service, 1993) and wetland function evaluation techniques (e.g., Adamus *et al.*, 1987, Bartoldus *et al.*, 1993). While elements from the evaluation techniques can be used in determining design criteria for specific functions (Marble, 1990, Bartoldus *et al.*, 1993), there is no guidance to aid wetland project managers in attaining wetland functions in other project development phases. The objective of this paper is to outline a method for attaining functional replacement goals in wetland restoration projects at specific project development phases.

2. Factors Affecting Wetland Functional Replacement

Wetland functions are the result of processes and characteristics occurring in the landscape (Brinson, 1993) and at the site (Adamus *et al.*, 1991). Conditions in the landscape affect the wetland hydrological, geological, chemical, and biological processes, thereby influencing the types and levels of functions performed by a wetland (Table I). Attainment of functional replacement requires that the restored wetland be placed in a landscape setting with the necessary conditions for the performance of the desired functions. For example, if sediment retention is a project goal, the restored wetland must be positioned in a disturbed or denuded watershed where it will receive runoff carrying sediments. This example can be used to illustrate the possibility that wetland projects can be placed where their capacity to perform a function can be overwhelmed. Most wetlands cannot perform the function of sediment retention where enough sediments are received and retained to cover and kill the vegetation. Wetland restoration project planners have relatively little design control over landscape features, and consequently, site selection criteria should be largely determined by the landscape features influencing the desired functions.

Once the landscape setting for the restored wetland has been selected, project planners can manipulate site characteristics (e.g., hydrology, energy, substrate, and vegetation) to determine the levels at which the wetland performs the desired functions. More nutrients will be retained, for instance, in a wetland designed to have no flow or sheet-flow than in a channelized wetland with high energy and turnover rates of water (Brown, 1985, Adamus *et al.*, 1991). Wetland project site characteristics are specified in the design criteria. Wetland functional replacement is not attained, however, until the design criteria are incorporated into a plan and the project successfully constructed.

Table I

Site selection (s) and design (d) features for restoration of wetland functions (based on Marble 1990). It should be noted that the level to which a feature influences the functional capacity of a wetlands differs with the specific function and wetland system (i.e., riparian, depressional, or fringe) (see Adamus *et al.* 1991, Marble 1990). Wetland functions codes: NRT - Nutrient Retention and Transformation; STR - Sediment and Toxin Retention; SS - Shoreline Stabilization; FFA - Floodflow Attenuation; GWR - Groundwater Recharge; PE - Production Export; ADA - Aquatic Diversity and Abundance; and WDA - Wetland Dependent Wildlife Diversity and Abundance.

	WETLAND FUNCTIONS							
	NRT	STR	SS	FFA	GWR	PE	ADA	WDA
LANDSCAPE								
Wetland System		s		s	s	d	s	s
Watershed Land Cover		s		s	s			s
Wetland/Watershed	s	s		s		s	s	
Watershed Size						s	s	s
Water Chemistry					s		s	s
Wetland Acreage							s	s d
Habitat Type and Interspersion							s d	s d
Human Disturbance							s	s
Fetch and Exposure		s	s			s		s
Erosive Conditions			s					
Water Source	s d	s d			s d		s d	
Nutrient Sources	s							
Watershed Soils				s	s			
pH						s		s

SITE HYDROLOGY								
Hydroperiod		d					s d	s d
Flood Extent-Duration		s d				s d	s d	
Artificial Drainage					d			s d
Outlet Characteristic	d	d		d	d	d	d	d
SITE ENERGY								
Sheet Flow			d	d		d		
Channel Gradient and								
Water Velocity	d	d				d	d	d
Shoreline Geometry			s d				d	d
SITE SUBSTRATE								
Substrate Type		s d				s d	s d	s d
SITE VEGETATION								
Vegetation Class and								
Form Richness	d	d	d	d		d	d	d
Vegetated Width	d	d	d			d		d
Water/Vegetation								
and Interspersion		d	d	d		d	d	d
High Plant Product.						d		
Vegetated Canopy							s d	s d
Diversity Enhancement							s d	s d
Special Habitat Feat.							d	d

3. Attaining Wetland Functional Replacement

Functional wetland restoration is the result of the successful implementation of a project plan that has been designed to optimize the performance levels of desired functions for a site in a given location. To accomplish this, project plans are based on a series of decisions that incorporate design criteria and site characteristics with ecological, engineering, and economic considerations (Figure 1). There are three critical phases in the decision sequence in which the features affecting wetland function must be incorporated: site selection, design criteria development, and plan development.

3.1 PHASE 1: SITE SELECTION

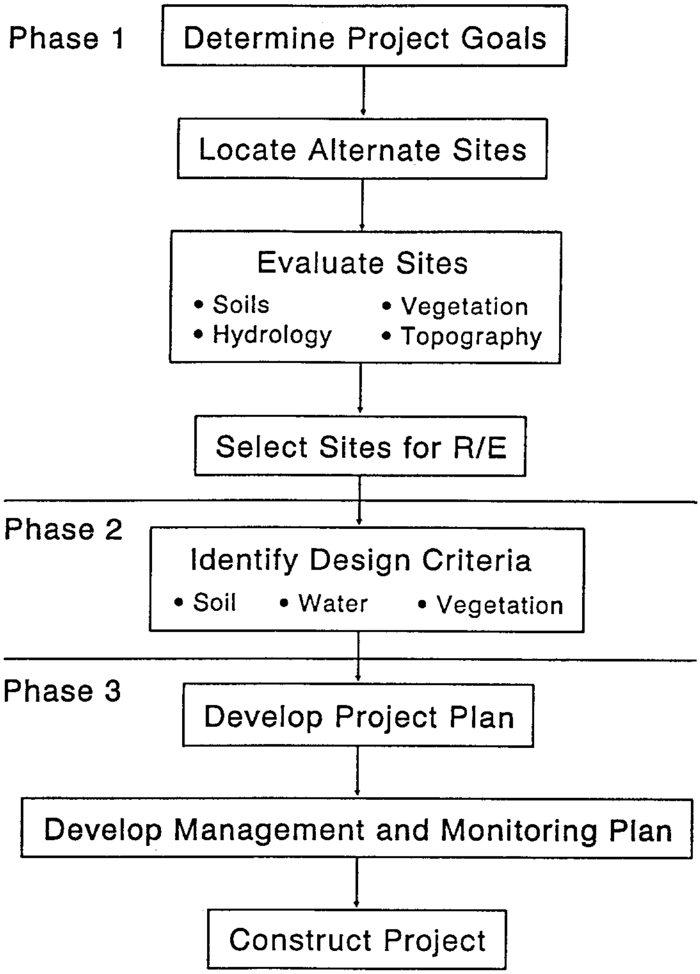
Proper site selection is an integral step in attaining desired wetland functions, as is evident from the various relationships of landscape features with different wetland functions (Table I). The ideal wetland restoration site for functional replacement has all of the landscape features required for the desired functions. In cases where the functions to be replaced were degraded by on-site activities, this is on the same site as where the functions were degraded or lost. The relationship between the existing landscape features and the wetland site remains intact and functions can be restored by on-site manipulations. In cases where it is not feasible to restore the wetland on the same site, alternate sites must be evaluated for their relative capacity to perform desired functions. The pertinent landscape features for the desired functions should be evaluated at each site and the sites prioritized on this basis (Figure 1). The site that has the optimum set of landscape features is the best candidate for successful functional wetland restoration. Depending on the availability of suitable sites to provide desired functions, however, site selection may or may not be goal driven in practice.

Practical limitations exist for wetland site selection, such as for mitigation projects resulting from a Section 404 regulatory action. The mitigation memorandum of agreement between the U.S. Army Corps of Engineers and U.S. Environmental Protection Agency specifies a preference for compensatory wetland mitigation to be on-site and in-kind wetland (Ainsley, this volume). Replacement of wetland functions, however, may not be possible in a developed landscape. For example, the wetland hydrology may be drastically altered by changes in runoff quantity and quality due to loss of permeable substrates. Habitat for a protected species may be lost due to lack of access to the wetland through the altered landscape. If site size or alteration by development make on-site restoration impractical, alternate sites must be selected for off-site and in-kind replacement. Limitations on alternate site selection such as availability or ownership may limit the possibilities for locating adequate areas for functional replacement.

Once the wetland project is situated in a viable setting, the next phase in the wetland decision sequence (Figure 1), is to determine design criteria for hydrology, substrate, energy, and vegetation.

FIGURE 1

Decision sequence for wetland restoration project development. Functional wetland restoration can be enhanced during three phases: site selection, identification of design criteria, and project plan development (after Palermo 1992).



3.2 PHASE 2: DESIGN CRITERIA DEVELOPMENT

Development of design criteria is the objective of the second project planning phase for functional wetland replacement. Design criteria specify the site conditions that must be established for the wetland to perform the desired functions. At this phase, the project planner begins to specify the hydrological conditions, current and wave energy, substrate characteristics, and vegetation composition and distribution that contribute to the wetland functions. To follow through with a previous example, if the functional goal is to improve water quality by retaining sediments received from upstream, the design criteria would specify the site conditions necessary to optimize the sediment retention capacity of the project site. Site hydrologic and energy characteristics could be created to reduce water energy and increase settling time (Table I). The design criteria might include creating a restricted outlet to increase retention time and a gentle gradient to reduce water velocity.

Design criteria serve several purposes. The first objective of design criteria is to specify the basic conditions required to establish a wetland. That is, the substrate must support wetland vegetation in areas that will experience at least saturated conditions during the growing season in most years. Design criteria for protection measures are also necessary to insure that destructive forces (e.g., energy, herbivory, fire) do not cause project failure, particularly during early project developmental phases. Finally, more specific design criteria for hydrology, substrate, energy, and vegetation determine how the functional goals of the wetland project will be attained.

Hydrologic design criteria are integral to the optimization of nearly all wetland functions (Table I). The depth, duration, seasonality, and extent of inundation are primary factors controlling most wetland ecological processes and functions, such as degree of anaerobiosis and plant productivity (Mitsch and Gosselink, 1986). Wetland hydrology is determined by a positive balance between sources and losses of water (Soil Conservation Service, 1992). The capacity of wetlands to perform most functions is improved, therefore, with either a constricting outlet or no outlet to allow for water retention. For example, functional capacities for nutrient retention/transformation and floodflow attenuation are improved with increased duration and extent of inundation resulting from reduced outflow (Adamus *et al.*, 1991).

Hydraulic design criteria determine water energy levels and thus, movement of particulate, nutrients, and toxins by water. Capacities of wetlands to perform many functions are affected by the frictional resistance of water, channelization, water velocity, or direction of impinging wave energy (Adamus *et al.*, 1991). For example, sheet flow has higher frictional resistance of water moving across the wetland floor than channelized water. As a consequence, sheet flow contributes to stabilization of shorelines, attenuation of floodflow, and export of organic matter production in wetlands (Table I).

Substrate design criteria for enhancing functional capacity of wetlands pertain primarily to substrate type (Table I) and underlying soils. Substrate nutrient content, depth, texture, and stability must be sufficient to support wetland vegetation, which in turn is important to the wetlands capacity to perform several functions (e.g., production export, wetland dependent habitat diversity and abundance). Underlying soils determine permeability rates for groundwater recharge (Freeze and Cheery, 1979).

Wetland vegetation contributes to many wetland functions (Table I). In addition to providing food, nesting areas, and cover for fish and wildlife, emergent and aquatic vegetation decrease water energy by increasing flow resistance (Adamus *et al.,* 1991) and modify substrates physically and chemically (Carpenter and Lodge, 1986). Vegetation design criteria for most functions often call for establishing a diversity of vegetation types that are interspersed with areas of open water (Table I).

3.3 PHASE 3: PROJECT PLAN DEVELOPMENT

Incorporation of function-specific design criteria into the project plan is the final phase in which functional restoration can be effectively planned (Figure 1). In order for the project to be built to perform the desired functions, the project planning team must use the design criteria to guide decisions regarding site-specific questions. Design criteria are too general in nature to be incorporated directly into a plan. For example, a certain width of vegetation between the upland and open water may be specified as a design criterion for the shoreline stabilization function in the target wetland. Additional design elements must be specified to insure that shoreline stabilization is achieved. For example, wetland plant species that are effective for stabilization must be selected that will tolerate the site conditions and a plan developed to establish the plants in the target location. Shoreline stabilization will not occur if plant material is obtained in poor health at the wrong time of year, installed incorrectly for the site conditions, or not protected during early development periods.

A wetlands restoration project plan is developed by comparing the site hydrology, energy, substrate, and vegetation conditions with the design criteria. The planning team considers factors such as the site ecology, economic limitations, engineering structures and techniques, and logistics to determine how to best incorporate the design criteria and site conditions into the project plan. Usually the site substrate, hydrology, and energy conditions are planned before the vegetation. The process should be iterative, however, so that all conditions are checked against the others for compatibility and feasibility. The result is a plan that is internally consistent for establishing the hydrology, substrate, and vegetation necessary for the wetland to perform the desired functions. The plans will be further developed into contract specifications to help ensure the design criteria are met as the project is being built.

An example follows to illustrate how a design criterion for diverse vegetation for wetland dependent wildlife habitat can be considered in the plan development phase.

4. Vegetation Establishment Plan Development: An Example

If a wetland is to be established to mitigate for loss of habitat for wetland dependent wildlife, several conditions need to be established. For example, the wetland should be situated in a landscape setting that provides wildlife access to the site (i.e., within migration range of target wildlife species) and environmental conditions that do not threaten the health or perpetuation of these populations. Design criteria may be specified to include a diversity of habitats on site to support a diversity of wildlife (Weins, 1989) at all stages of their life histories, such as feeding, winter cover, and breeding (Heitmeyer *et al.,* 1984, Frazer *et al.,* 1990). Establishment of habitat diversity requires the establishment of diverse vegetation.

Once the substrate and hydrological features have been planned, the vegetation plan can be developed to enhance diversity (Figure 2). The vegetation planning procedure begins by determining whether desirable vegetation exists on or near the project that is capable of colonizing the site. If desirable plant species will not naturally colonize, a plan to establish vegetation must be developed. The following decision sequence illustrates considerations for attaining diverse vegetation at all points in the vegetation establishment plan development phase.

4.1 SPECIES SELECTION

The standard guidance for species selections is to use locally occurring species that tolerate planned site conditions and meet project objectives (Hammer, 1992, Soil Conservation Service, 1992). If the project objective is to maximize species diversity then species within each moisture zone should be selected with consideration of plant form, mode of reproduction, and stratum. In marshes, herbaceous plant forms need to be compatible. For example, a tight sod forming grass species may inhibit growth and reproduction of slower growing or single-stemmed species. If maximizing structural diversity is the priority, then herbaceous plants and midstory tree species should comprise the majority of the selected species. These species are often shade tolerant species, and attention may be required to the provision of nurse plants to ameliorate initially harsh site conditions (see below).

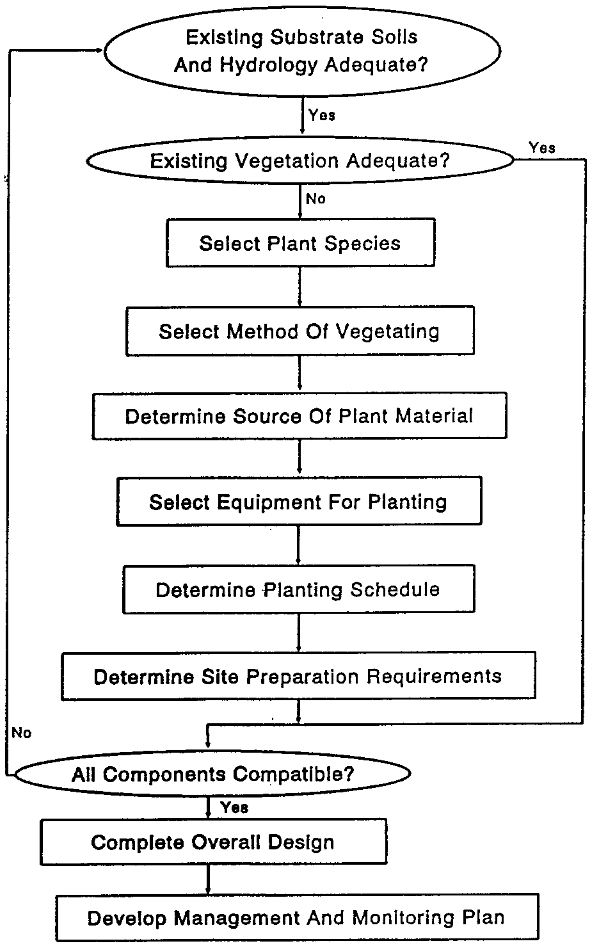
4.2 PLANT SOURCE AND ACQUISITION

Wetland plant material is acquired from natural sites and from commercial sources. Seeds and vegetative propagules collected from local natural wetlands are likely to be tolerant of regional conditions and have the genetic diversity necessary to adjust to changing site conditions. Collection of plant materials from natural areas is, however, limited by the degree of site disturbance. Seeds can be collected with little impact, but digging of vegetative propagules is not advisable unless the site is going to be developed. It is desirable, therefore, to have as great a diversity of commercially available plant material as possible.

The most important factors that restrict supply of diverse plant materials from commercial nurseries are a lack of demand and limited knowledge about

FIGURE 2

Detailed decision sequence for wetland vegetation establishment in the project plan development phase (after Palermo 1992).



species handling requirements. These factors are interrelated, and so must be addressed together. Demand for diverse plant material needs to be increased by wetland project managers who are aware of the advantages of using such material. Wetland planting guides which consolidate important information regarding plant selection and characteristics are scarce (e.g., Thunhorst, 1993), and additional sources are needed. Much information on common species simply does not exist. Species-specific experience is required on techniques for plant propagation, handling, establishment, and management.

4.3 PLANTING METHODS

An effective means of actively obtaining natural species diversity in a wetlands project is to move topsoil containing seeds and vegetative propagules from a natural wetland to the wetland project site. Topsoil can be moved with the plants intact, either as sod (Figure 3) or in smaller plugs. Successful marshes have been created by using the topsoil as a mulch and spreading it over a contoured ground surface (Figure 4). Caution needs to taken, however, that stockpiling time is minimized and that stockpiles are not placed in wetlands (Garbisch, 1986). In addition, careful matching of hydrclogical conditions between topsoil donor areas and recipient areas facilitates the formation of vegetation zones in the project area. Use of topsoil from natural wetlands is limited to cases where the donor wetland will be developed.

4.4 PLANTING SCHEDULE

Certain plants, primarily shade-tolerant species, grow best in the low-light and cooler interiors of swamps. These species survive and grow best when protected from harsh conditions that are commonly found in wetland projects. These plants require the presence of hardier plants that may provide shade, protection from wind, or improved soil fertility. These cover or nurse crops can be planted at the same time or prior to the establishment of less tolerant species (Clewell and Lea, 1990). Interplanting species after the establishment of an initial complement of plants prolongs the involvement period with the project, but greatly increases the potential for using species not commonly used in wetland projects.

4.5 SITE PREPARATION

Species diversity in natural wetlands is greater where the surface is uneven. Hummocks, fallen logs, and depressions provide a variety of hydrological conditions which are exploited by many species. For example, a plant growing on a hummock can escape long periods of inundation it would experience directly on the wetland floor. Creation of a rough surface in a wetland project does not look "neat", but it adds a feature found in diverse natural areas.

(a) (b)

FIGURE 3
Movement of intact pieces of sod salvaged from wetlands that will be developed and moved to restored wetlands is an innovative technique for establishing diverse wetland vegetation. A) Sod mat on modified frontend loader being moved to a flatbed truck for transport. B) Sod reconstructed in center of restored wetland.

(a) (b)

FIGURE 4
Spreading topsoil from a donor wetland that will be developed on a created or restored wetland is a technique that has been successfully used for rapidly establishing wetland vegetation over relatively large areas. A) The floor of the created wetland soon after the wetland mulch was applied. B) The dense wetland vegetation that became established within two years. Caution should be used not to transfer undesirable or aggressive species to the restored wetland with the topsoil seedbank.

5. Conclusions

Success of functional restoration can be enhanced with a multi-phased approach to wetland project planning. Proper site selection insures that a wetland is situated where there is the potential to perform a function. Incorporation of functional design features into design criteria and project plan development further optimizes the potential for a site to perform desired functions. All three phases are interrelated and are integral to the replacement of wetland functions in restoration projects.

While decision sequences for wetland project planning such as presented here will help attain functional wetland restoration and establishment, it should not be overlooked that we are a long way from fully understanding wetland ecological processes and functions. We may be even further from being able to restore wetland functions similar to natural systems. It is clear that there is no simple solution. The effort will require continuing research and experience. Functional wetland replacement is a goal worthy of this commitment.

Acknowledgements

This work was sponsored by the U.S. Army Corps of Engineers Wetlands Research Program. Helpful comments on earlier drafts were received from Candy Bartoldus, Carl Trettin, and Dan Smith. Ann Marble and Mike Palermo were generous with their consent to incorporate their work into this paper.

References

Adamus, P. R., Clairain, E. J., Smith, R. D., and Young, R. E.: 1987: *Wetland evaluation technique (WET) Volume II: Methodology (Operational Draft Report).* Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Adamus, P. R., Stockwell, L. T., Clairain, E. J., Morrow, M. E., Rozas, L. P., and Smith, R. D.: 1991. *Wetland Evaluation Technique Volume 1: Literature Review and Evaluation Rationale*, Wetlands Research Program Technical Report WRP-DE-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, p. 287.

Ainsley, W. B.: 1995. Rapid wetland functional assessment: its role and utility in the regulatory arena, *Water, Air, and Water Pollution* this volume.

Bartoldus, C. C., Garbisch, E. W., and Kraus, M. L.: 1994. *Evaluation for planned wetlands.* Environmental Concern. St. Michaels, MD. p. 179.

Brinson, M. M.: 1993a. *A Hydrogeomorphic Classification for Wetlands*. Wetlands Research Program Technical Report WRP-DE-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, p. 79.

Brinson, M. M.: 1993b. Changes in the functions of wetlands along environmental gradients, *Wetlands* 13:65-74.

Brown, R. G.: 1985. Effects of wetland channelization on runoff and loading. *Wetlands* 8:123-133.

Clewell, A. F. and Lea, R.: 1990. Creation and restoration of forested wetland vegetation in the southeastern United States, p. 195-232 In: Kusler, J. A. and Kentula, M. E. (eds), *Wetland Creation and Restoration: the Status of the Science*, Island Press, Washington, D. C.

Crabtree, A., Day, E., Garlo, A., Stevens, G.: 1992. Evaluation of wetland mitigation measures Volume 1: Final report. Federal Highway Administration Report No. FHWA-RD-90-083, U.S. Department of Transportation, Washington, D. C., p. 353.

Carpenter, S. R. and Lodge, D. M.: 1986. Effects of submersed macrophytes on ecosystem processes. *Aquatic Botany* 20:341-370.

Frazer, C., Longcore, J. R., McAuley, D. G.: 1990. Habitat use by post-fledgling American Black ducks in Maine USA and New Brunswick Canada. *Journal of Wildlife Management* 54: 451-459.

Freeze, R. A. and Cherry J. A.: 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, NJ. p. 604.

Garbish, E. W.: 1986. Highways and wetlands: Compensating wetlands losses. Federal Highway Administration Report No. FHWA-IP-86-22, U.S. Department of Transportation, Washington, D. C., p. 60.

Hammer, D. A.: 1992. *Creating freshwater wetlands.* Lewis Publishers, Boca Raton, FL. p. 298.

Heitmeyer, M. E. Fredrickson, L. H., and Krause, G. F.: 1991. Water relationships among wetland habitat types in the Mingo Swamp, Missouri. *Wetlands* 11:55-66.

Kusler, J. A. and Kentula, M. E. (eds): 1990. *Wetland Creation and Restoration: the Status of the Science*, Island Press, Washington, D. C., p. 594.

Marble, A. D.: 1990. *A Guide to Functional Wetland Design*, Federal Highway Administration Report No. FHWA-WP-90-010, U. S. Department of Transportation, Washington, D. C., p. 222.

Marburger, J. E.: 1993. *Wetland plants: materials, technology, and development.* U.S. Department of Agriculture, Soil Conservation Service. p. 54.

Mitsch, W. J. and Gosselink, J. G.: 1986. *Wetlands*, Van Nostrand Reinhold Company, Inc., New York, N.Y. p. 539.

Palermo, M. R.: 1992. Wetlands engineering: Design sequence for wetlands restoration and enhancement. Wetlands Research Program Technical Note WG-RS-3.1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, p. 4.

Soil Conservation Service: 1992: *Engineering field handbook Chapter 13: Wetland restoration, enhancement, or creation.* U.S. Department of Agriculture 210-EFH,1/92, Washington, D. C. p. 79.

Thunhorst, G. A.: 1993. *Wetland planting guide for the northeastern United States: Plants for wetland creation, restoration, and enhancement.* Environmental Concern, Inc. St. Michaels, MD p. 179.

Wiens, J. A. 1989. The ecology of bird communities Volume 1: Foundations and patterns. Great Britain, Cambridge University Press. p. 372.