NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP Report 379

Guidelines for the Development of Wetland Replacement Areas

Transportation Research Board
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Guidelines for the Development of Wetland Replacement Areas

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation officials, or the Federal Highway Administration, U.S. Department of Transportation.

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FOREWORD

By Staff
Transportation Research Board

This report describes a process for locating, designing, constructing, maintaining, and monitoring wetland replacement areas. This report is supplemented by appendixes that discuss various aspects of wetland creation and restoration. The *Guidelines* will be of interest to those involved with wetland replacement areas (e.g., engineers, environmentalists, planners, and regulators), both as a concept and as an actuality, once it is obvious that the creation of a replacement wetland is necessary. Although not explicitly within the scope of this study, *the Guidelines* also will be useful to those involved with wetland banks—the development of wetlands that could be used to compensate for future takings elsewhere.

Planning for highway projects frequently involves consideration of several mitigative alternatives to address adverse impacts to wetland resources. One alternative often used requires the development of wetland replacement areas as compensation for wetlands lost because of highway development projects.

Although considerable information was available on the subject of wetland replacement—both in documented form and in undocumented experience and practice—much of this information was fragmentary and dispersed throughout the country, or it had not been fully evaluated. Therefore, current information could not easily be used for locating, designing, constructing, maintaining, or monitoring wetland replacement areas. To ensure effective implementation of this important mitigative alternative, transportation planners, designers, environmental staff, and other users needed ready access to this information. Therefore, there was a need to synthesize the state of the art and, from this synthesis, to develop a recommended process for replacing wetlands.

Accordingly, URS Consultants, Inc., along with Environmental Concern, Inc., under NCHRP Project 25-3, "Guidelines for the Development of Wetland Replacement Areas," developed recommended guidelines. The *Guidelines* contain a well-defined wetland replacement process, including techniques for locating, designing, constructing, monitoring, and maintaining wetland replacement sites. Detailed appendixes on the various facets of creating replacement wetlands or restoring existing wetlands supplement the main text.

The *Guidelines* also will be helpful to those wishing to create wetland banks that could be used for trade at a later date when the elimination of an existing wetland is unavoidable. Neither the *Guidelines* nor this Foreword is intended as commentary on the merits of wetland banking to mitigate the unavoidable elimination of wetlands; however, if a decision is made to implement a wetland bank, the *Guidelines* will be useful in the physical creation of the compensating wetlands.

Special Note to Readers

A *Synonymized Checklist of the Vascular Flora of the United States, Canada, and Greenland, Volumes 1 and 2,* by John Kartesz, was published in 1994 by Timber Press, Oregon. The scientific nomenclature of several species used in wetland creation and restoration has been revised. Listed below are scientific name changes of some of the more commonly used species listed in the *Guidelines.*

PREVIOUS SCIENTIFIC NAME	NEW SCIENTIFIC NAME
Acer floridanum	*Acer barbatum*
Agrostis alba	*Agrostis gigantea*
Agrostis Alba var. stolonifera	*Agrostis stolonifera*
Baccharis glutinosa	*Baccharis salicifolia*
Bidens polylepsis	*Bidens aristosa*
Cladium jamaicense	*Cladium mariscus*
Cornus foemina racemosa	*Cornus racemosa*
Frankenia grandifolia	*Frankenia salina*
Grindelia humilis	*Grindelia hirsutula*
Halodule wrightii	*Halodule beaudettei*
Hibiscus palustris	*Hibiscus moscheutos*
Limonium nashii	*Limonium carolinianum*
Nasturium officinale	*Rorippa nasturium-aquaticum*
Nuphar luteum	*Nuphar lutea*
Phragmites communis	*Phragmites australis*
Quercus nuttallii	*Quercus texana*
Salix lasiandra	*Salix lucida*
Scirpus lacustris ssp. validus	*Scirpus tabernaemontani*
Scirpus validus	*Scirpus tabernaemontani*
Sparganium emersum	*Sparganium angustifolium*
Viburnum recognitum	*Viburnum dentatum*

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ACKNOWLEDGMENTS

This project required a team effort to generate the final product, a set of guidelines for the development of wetland replacement areas. Many individuals across the disciplines made substantial contributions to these *Guidelines*, and we want to acknowledge their efforts here. We thank all those who generously gave advice, referrals, and other support during the project.

URS Consultants was responsible for portions of the research, project management, and preparation of the *Guidelines*. Thomas J. Denbow was the Co-Principal Investigator for URS Consultants (Cleveland, Ohio) and overall Project Manager for NCHRP Project 25-3. Donna Klements helped to complete the background research. Daniel W. Rothman, P.E., Rothman Environmental Engineering (formerly with URS Consultants, Inc., Cleveland, Ohio), prepared the hydrology portions of the document (Appendix E). Joseph H. Chadbourne and Mary M. Chadbourne, Chadbourne & Chadbourne, Inc. (Bainbridge Township, Ohio), were responsible for text layout and editing and provided invaluable assistance to URS and EC in document design and editorial content.

This document would not have been possible without the expertise of Edgar W. Garbisch, Ph.D., President of Environmental Concern (St. Michaels, Maryland) and Co-Principal Investigator for preparation of the *Guidelines*. Dr. Garbisch has played a major role in laying the scientific and applied technical groundwork for wetland restoration and creation in the United States. From his years of experience in this field, he brought invaluable technical information and a pragmatic approach to the daily aspects of wetland design and construction. The staff at EC developed and refined the subject matter of the *Guidelines*. Special thanks go to Candy C. Bartoldus, Ph.D.; Gwendolyn A. Thunhorst; Mark L. Kraus, Ph.D.; and Donald R. MacLean.

Finally, we gratefully acknowledge the patience, guidance, and contributions of Mr. Crawford Jencks, the Senior Program Officer for the NCHRP; the Program Panel; and the NCHRP throughout the preparation of the *Guidelines*.

GUIDELINES FOR THE DEVELOPMENT OF WETLAND REPLACEMENT AREAS

SUMMARY

OBJECTIVES AND SCOPE

This report presents procedural guidelines and techniques for state highway agencies (SHAs), their consultants, and others for the design and construction of replacement wetlands. It synthesizes experience and research through 1991 and recommends an eight-step process for project sponsors to follow when undertaking wetland replacement. That process includes steps for locating, designing, constructing, monitoring, and maintaining replacement wetlands. For purposes of this manual, "wetland replacement" is defined as a design or implemented design for a constructed, restored, or enhanced wetland.

The researchers who prepared the report carried out the research in four separate tasks. They (1) examined existing wetland replacement technical literature and scientific data; (2) interviewed personnel with wetland replacement experience; (3) developed a recommended procedure for a wetland replacement process (WRP); and then (4) prepared this final document, *Guidelines for the Development of Wetland Replacement Areas*, Report 25-3, for the National Cooperative Highway Research Program (NCHRP).

This report is a technical document. As such, it does not focus on wetland regulations and policies. Toward the end of the Introduction, however, the research team identifies steps in the WRP where state and federal wetland regulations and policies may apply.

The research team assumes that before moving forward with a wetland replacement project, users of this report will have complied with applicable federal, state, and local regulations and policies requiring wetland impact avoidance and minimization.

ORGANIZATION

The *Guidelines* document consists of two parts. The first part (Chapters 1 through 8) describes the eight steps of the recommended WRP. These steps are not expected to change with time. The goal of this part of the *Guidelines* is to help project sponsors understand the basics of the WRP without sorting through region-specific and technical information.

The second part of the *Guidelines*, the appendixes, contains general region- and design-specific technical information on wetland replacement. From it, users can select what is relevant to their own projects. Because this information is expected to change with time, the appendixes are organized to allow each to be updated without reprinting the entire document.

WETLAND REPLACEMENT PROCESS	*GUIDELINES* CHAPTERS
	Introduction • Objectives and scope of the *Guidelines* • Overview of the Wetland Replacement Process • Defining wetland success
Step 1: Assessing Wetland Functions & Setting Goals and Objectives • Complete regulatory agency coordination • Identify existing wetland functions and values • Identify permit requirements • Set replacement wetland goals and objectives	**Chapter 1: Assessing Wetland Functions & Setting Goals and Objectives** 1.1 Decision for Wetland Replacement 1.2 Wetland functions and values 1.3 Selection of a tool for data collection 1.4 Setting goals and objectives for the replacement wetland
Step 2: Selecting the Site • Identify site selection criteria • Complete initial site screening • Identify preferred sites • Conduct site feasibility evaluation • Confirm goals and objectives • Select recommended site	**Chapter 2: Selecting the Site** 2.1 Introduction 2.2 General considerations 2.3 Information sources for site screening 2.4 Screening and selection of alternative sites 2.5 Analysis of selected alternative sites 2.6 Site selection 2.7 Documenting the site selection process
Step 3: Preparing the Conceptual Wetland Replacement Plan • Prepare plan sheets & notes • Estimate costs to construct/monitor • Demonstrate sustaining hydrology exists • Identify major plan elements • Identify plant communities • Prepare summary information	**Chapter 3: Preparing the Conceptual Wetland Replacement Plan** 3.1 General considerations 3.2 Reasons for developing a conceptual wetland replacement plan 3.3 Content of the conceptual wetland replacement plan 3.4 Timing the submittal of the conceptual plan
Step 4: Obtaining Additional Information for Final Construction Plans and Specifications • Collect site-specific data for financing plans • Complete hydrologic monitoring • Identify problem wildlife • Complete soil seed bank studies	**Chapter 4: Obtaining Additional Information for Final Construction Plans and Specifications** 4.1 Introduction 4.2 Reference wetlands 4.3 Soil seed bank studies 4.4 Hydrologic monitoring 4.5 Assessment of problem wildlife 4.6 Assessment of potential vandalism problems
Step 5: Preparing Construction Plans & Specifications • Prepare summary report • Prepare hydrology report • Prepare construction and grading plans • Prepare landscaping plan • Identify erosion & sediment control measures	**Chapter 5: Preparing Construction Plans and Specifications** 5.1 Accuracy and clarity 5.2 Timing the submittal of the conceptual plan
Step 6: Constructing the Replacement Wetland • Complete site grading and landscaping • Monitor construction contractor • Prepare change orders (if required) • Document as-built plans	**Chapter 6: Constructing the Replacement Wetland** 6.1 Overview of wetland construction 6.2 Construction monitoring and plan modifications 6.3 As-built plans 6.4 Problems encountered when constructing wetland replacements
Step 7: Maintaining the Replacement Wetland • Stabilize soils • Adjust water flow/availability • Establish vegetation management program • Remove debris	**Chapter 7: Maintaining the Replacement Wetland** 7.1 Responsibilities for wetland replacement maintenance 7.2 Categories of maintenance activities 7.3 Conclusion
Step 8: Monitoring the Replacement Wetland and Reporting • Initiate site monitoring • Prepare report	**Chapter 8: Monitoring the Replacement Wetland and Reporting** 8.1 Overview of monitoring issues 8.2 The recommended WRP monitoring approach & criteria for successful replacement 8.3 Acceptable disparities between the replacement wetland and the plans and specifications 8.4 Rationale for the recommended monitoring approach

Figure 1. Overview of the WRP.

PREVIEWING THE CONTENTS OF THE *GUIDELINES*

The research team encourages users of the *Guidelines* to review Figure 1 to identify chapters that may be important to them and to become familiar with the information requirements of Steps 1 through 8 in the WRP. Experienced wetland replacement professionals may wish to go directly to the appendixes that treat their individual areas of interest. After that, the research team encourages users to preview each chapter by paging through its text and reading the major headings. These headings will do the following:

- Highlight major topics covered in the chapter and
- Identify specific procedures that users should be considering at this stage in the WRP.

Once familiar with the contents of the chapters, users will be prepared to work through the relevant portions of the *Guidelines* and the corresponding appendixes.

Important terms in Chapters 1 through 8 that may be unfamiliar to some readers appear in the Glossary with definitions; where appropriate, those definitions are amplified in the text.

SOURCES OF INFORMATION AND DATA

The authors of this report are referred to variously throughout the manual as the "research team" or the "researchers."

Users also will find generic and specific references to the personnel who actually perform work on wetland replacement. Generically, they are "project sponsor(s)," "project staff," or "project personnel." Specifically, they are "landscape architects," "hydrologists," "construction and maintenance personnel," and "consultants."

This manual reflects the professional experience of the research team, whose members have worked to bring many wetland replacement projects to completion (Acknowledgments). Statements attributable to other professionals in the field are documented in the text. An important objective of the research effort was to validate findings through the review of technical literature, consultation with practitioners, and direct experience at replacement sites. Thus, the research team has provided confirmed facts about wetland replacement areas or it has referred readers to the work of others on particular aspects of wetland replacement. Readers should regard all other statements in the *Guidelines* as the research team's best professional opinion, except where noted.

The researchers qualified certain statements in the text where they believed the reader could be confused about what the team's stated professional experience is versus what is a generally accepted fact. Therefore, if users of the *Guidelines* still have questions about a specific issue in the text or the appendixes, they should consult appropriate professionals about their questions, such as experts in wetland science, wetland hydrology, wetlands biology, or landscape architecture.

RELATIVE SUCCESS IN WETLAND REPLACEMENT

Users of the *Guidelines* should know that success in constructing specific replacement types varies considerably. Kusler and Kentula's (1990) summary of wetland replacement experience (from highest to lowest success) highlights the variability of this experience. Success relates to the extent of actual experience by practitioners and to the overall probability of success for the specific wetland replacement type. This summary is reviewed as follows:

- Estuarine Marshes: The amount of experience and documentation for replacement of these tidal salt, brackish, and fresh marshes indicates that the probability of success is high. Generally, it is easy to determine the hydrology of the area. Often, only a few wetland plant species are required (salt marshes). Overall, these species are relatively easy to establish and plant materials are available from commercial sources, subject to advance ordering requirements. Problems can arise, however, with narrow tidal ranges, wind-controlled tides, and hypersaline soils.
- Coastal Marshes: The same problems and probability of success with wetland replacement that apply to estuarine marshes, above, apply to coastal marshes.
- Freshwater Marshes along Lakes, Streams, and Rivers: As is the case with estuarine and coastal marshes, wetland replacement experience and documentation indicate the probability of success is high because the necessary hydrologies for the wetland replacements are readily understood. Problem areas include incursion by exotic plant and animal species.
- Isolated Marshes Predominantly Supplied by Surface Water: Experience and documentation for replacement of these wetlands are limited compared to the previous three types. Therefore, the probability of success is lower. Problems arise from an often unpredictable stormwater supply and the need for active management of the hydrology. Establishing the desired plant communities can also be difficult, particularly during droughty years.
- Forested Wetlands along Lakes, Streams, and Rivers: Limited replacement experience and documentation are available for these wetland types. The necessary hydrologies for the wetland replacements are readily understood, but managing forest development over many years is a prime problem in replacing these areas. Other problems include managing diverse vegetation in upper- and lower-story growth and in controlling exotic plants and animals.
- Isolated Freshwater Wetlands Predominantly Supplied by Groundwater: Experience and documentation are limited, except for replacement projects involving prairie potholes. The major problem involves hydrology, determining what groundwater is available at a replacement site and, once that is known, providing the necessary groundwater to the site.

Users of the *Guidelines* also should understand that the ability to design and construct replacement wetlands is an emerging applied science. Scientific understanding of the specific wetland types and technical understanding about how to restore and create specific wetland types and functions are evolving and growing. Because much of the information incorporated in this report is current only through 1991, users should be aware that more recent regional and local technical experience may exist that will help project sponsors complete successful wetland replacement projects. The research team encourages project sponsors to consult with experienced wetland replacement professionals about replacement projects.

Finally, users of this manual must be aware that simply following the WRP cannot and will not guarantee success. Readers should not use the *Guidelines* as a "cookbook" or as a complete or accurate source of "standards," or boilerplate for wetland replacement. Such misuse could result in costly mistakes and even project failures. However, users of the manual who follow the procedures and general design principles identified here (e.g., the gen-

Wetland replacement projects are site-specific and function-specific. The *Guidelines* should not be used as a "cookbook." Such misuse could result in costly mistakes and project failures.

eral applicability of relatively flat slopes for replacement [i.e., 10 to 1 or flatter] to encourage the development of boundary zones and irregular vegetation patterns) can expect to avoid many of the more common problems and mistakes that have occurred.

Users are warned that for some wetland types, particularly those noted previously by Kusler and Kentula (1990), successful replacement will be difficult to achieve. As such, project sponsors attempting such mitigation should be prepared for a major effort of cost and time when undertaking them, an undertaking many project sponsors may want or choose to avoid.

PERSONNEL REQUIREMENTS FOR WETLAND REPLACEMENT PROJECTS

In certain situations and for some wetland types, users of the *Guidelines* may require training and technical input from persons with experience in the broad range of subjects related to the particular situation or wetland type. These areas of expertise include the following:

- Terrestrial ecology,
- Surface and groundwater hydrology,
- Geology and geochemistry,
- Soils,
- Highway engineering and design,
- Landscape architecture,
- Construction methods and management, and
- Real estate appraisal and negotiation.

A team approach with experienced members who have a combination of technical skills in these areas works best to achieve success in wetland replacement. Simple projects might be successfully designed and implemented by small teams, even by one or two well-experienced members. The research team has found that in many instances when the project hydrology is straightforward and validated by biological benchmarks (Chapter 2), successful wetland replacement can be designed by one or more persons with experience only in wetlands biology, ecology, and landscape architecture. A project involving complex hydrology, site preparation, and water control and supply measures will require additional design and technical skills.

OVERVIEW OF THE WRP

Project sponsors use wetland replacement, or "wetland mitigation," to offset wetland losses (Appendix A). But is there a technical procedure to follow in replacing a wetland? The research team recommends an organized progression of steps that begins with evaluating the functions of the wetland to be impacted and then setting goals and objectives for the replacement wetland. The steps conclude with monitoring the replacement wetland to determine how it complies with the project's plans and specifications. The WRP as described in these *Guidelines* and summarized in Figure 1 represents a systematic approach for successful wetland replacement, on the basis of the research and experience of the researchers.

The research team recognizes that the WRP may not meet the needs of all project sponsors. Some sponsors may be subject to specific state regulations and wetland mitigation policies that have led them to develop their own procedures for wetland replacement (e.g., the Pennsylvania Department of Transportation [1990] and the Idaho Department of Transportation [1990]). In such cases, some steps in the WRP might be eliminated or replaced by state-specific requirements. But generally speaking, the following eight steps should apply to most project sponsors who undertake wetland replacement.

The Eight Steps of the WRP

The following steps comprise the WRP (with corresponding *Guidelines* chapters indicated):

- Step 1: Assessing Wetland Functions and Setting Goals and Objectives (Chapter 1),
- Step 2: Selecting the Site (Chapter 2),
- Step 3: Preparing the Conceptual Wetland Requirement Plan (Chapter 3),
- Step 4: Obtaining Additional Information for Final Construction Plans and Specifications (Chapter 4),
- Step 5: Preparing Construction Plans and Specifications (Chapter 5),
- Step 6: Constructing the Replacement Wetland (Chapter 6),
- Step 7: Maintaining the Replacement Wetland (Chapter 7), and
- Step 8: Monitoring the Replacement Wetland and Reporting (Chapter 8).

Although the research team devotes a chapter in the *Guidelines* to each of these steps, each is summarized as follows:

- Step 1—Assessing Wetland Functions and Setting Goals and Objectives. This step identifies the functions provided by the wetland that is to be lost and sets project goals and objectives for the replacement wetland. At a minimum, these should address replacing the lost wetland's functions.
- Step 2—Selecting the Site. The project sponsor identifies one or more sites that meet all the physical and hydrological requirements for a successful replacement wetland. The sponsor selects the final site on the basis of the site's capacity to achieve the replacement wetland goals and objectives while minimizing costs.
- Step 3—Preparing the Conceptual Wetland Replacement Plan. During this step, a project sponsor prepares a conceptual plan for the selected site, producing that plan at a scale suitable for review by project staff and possibly wetland regulatory personnel. The conceptual plan for the replacement wetland must include the design elements that will provide the desired wetland functions as stated in the project goals and objectives. To accomplish this, the project sponsor will have had to verify that the functions provided by the wetland to be lost can, in fact, be provided by the replacement wetland. To do so, the project staff will have assessed the wetland functions possible under various alternative design sketches for the replacement site and then arrived at the best single design for replacing those functions. This design appears in the conceptual plan.
- Step 4—Obtaining Additional Information for Final Construction Plans and Specifications. Project staff collect site-specific data to prepare final plans and specifications. The information collected usually includes accurate site-specific topography and hydrologic and hydraulic data.
- Step 5—Preparing Construction Plans and Specifications. Construction plans and specifications provide all details regarding the wetland construction—these documents are

Users are cautioned that delaying potentially critical evaluations recommended in Step 2 to later steps may result in costly delays, a determination that the site may not be usable, or both.

project-specific and must not be generated from boilerplate. From these details, project staff generate the bid documents, which direct the actual construction of the wetland and serve to verify that the "as-built" project complies with the project design. Because the requirements for constructing a given replacement wetland are often unique, these documents must provide important information on the construction sequencing and other considerations and conditions unique to the project.

- Step 6—Constructing the Replacement Wetland. This step includes site grading, substrate preparation, landscaping, and documenting the construction in as-built plans. Project sponsors and, where required, regulatory agencies, should approve in advance any deviation from the plans and specifications. Contractors and supervising personnel familiar with wetland replacement should complete all the work, coordinating their activities with regulatory agencies, as required.
- Step 7—Maintaining the Replacement Wetland. Generally, maintenance involves ongoing activities to protect the integrity of the replacement wetland, including water elevation monitoring, control of erosion and nuisance plants, and monitoring of animal species, water-control structure maintenance, litter and debris removal, watering, reseeding, and other actions. The specified maintenance activities undertaken during the postconstruction phase of the project ensure that the replacement wetland functions as it was designed to function. If maintenance personnel identify problems, steps can be taken to resolve them.
- Step 8—Monitoring the Replacement Wetland and Reporting. A project sponsor might adopt one of many monitoring protocols or the research team's recommended monitoring approach (Chapter 8). If there is a literature-validated relationship between the wetland functions to be lost and the design elements used to create those functions in the replacement wetland, then the replacement site will provide the functions if the project is built according to construction plans and specifications. Thus, if postconstruction monitoring confirms that the replacement wetland conforms with the construction plans and specifications, then the replacement project will usually be successful. In Step 8, monitoring personnel should make periodic reports for the project sponsor's internal control and to meet regulatory requirements. Such reports describe the status of the wetland replacement project and highlight items that require maintenance.

Critical Factors to Remember During the WRP

The two most important factors associated with successful wetland replacement projects are as follows:

- The hydrology associated with the wetland replacement project is clearly understood and known to be reliable.
- The construction plans and specifications are site-specific and sufficiently detailed and are followed explicitly during construction.

In addition to these factors, the research team sees Step 1 ("Assessing Wetland Functions and Setting Goals and Objectives") as critical to successful wetland replacement. The goals

As long as supporting hydrology exists at a replacement site, success is possible despite errors that may occur.

and objectives set there guide the balance of the WRP and, therefore, the other steps flow logically from Step 1. In Step 2 ("Selecting the Site"), project staff gather information about the hydrology, its verification, and grades relative to the site hydrology. Using hydrological data gathered in Step 2 and other information gathered in Step 4 ("Obtaining Additional Information for Final Construction Plans and Specifications"), project staff develop the site-specific construction plans and specifications in Step 5 ("Preparing Construction Plans and Specifications"). The verifications the project staff make in Steps 2, 3, and 5 supply evidence that the goals and objectives of Step 1 will be met. Such a sequence of verifications helps ensure a successful project. Finally, Step 7 ("Maintaining the Replacement Wetland") and Step 8 ("Monitoring the Replacement Wetland and Reporting") are important to maintenance of and to verifying that the constructed wetland continues to provide the replacement functions established by the goals and objectives in Step 1. Ideally, a project that is well designed and built according to the construction plans and specifications will require little, if any, postconstruction maintenance and will achieve the initial goals and objectives established in Step 1.

What functional evaluation method should project sponsors use in Steps 1, 2, 3, and 5? The research team believes that any one of the following are appropriate:

- Best professional judgement,
- One of many wetland evaluation procedures currently or recently used in the United States (Chapter 2, Table 2), or
- The procedure presented in Appendix J of the *Guidelines* for evaluating existing wetlands and for developing wetland replacement plans that include design elements that will provide the selected wetland functions.

The research team recognizes that not all steps may apply to all projects. Steps 1, 3, 8, or combinations thereof might be modified. Steps 1 and 3 might be eliminated to meet the specific needs and interests of certain project sponsors, while the other steps in the WRP probably will apply to all SHAs. Some project sponsors may choose to eliminate Step 3 or 4 or both and go directly to Step 5, particularly when regulatory agencies do not require a review of the conceptual plan or when the necessary design information can be collected during Step 5.

Furthermore, "in-kind" wetland replacements (Appendix A) also may deviate from the steps followed in the WRP, because in-kind defines the goals and objectives of the replacement wetland. For example, Steps 1 and 3 may be unnecessary provided other wetland enhancement measures are not pursued simultaneously with constructing the in-kind replacement site. Finally, if the recommended monitoring protocol in Step 8 is not acceptable to a project sponsor or regulatory agency, another one may be identified and pursued.

Involvement of Regulatory Personnel

Although this manual focuses on the technical aspects of wetland replacement, the WRP itself may involve wetland regulations and policies. However, each project sponsor can expect to work differently with wetland regulatory personnel. Regulatory personnel might logically become involved with the replacement project at the following points in the WRP:

- Step 1. Regulatory personnel may be needed to obtain agreement on functional evaluation and replacement goals and objectives.
- Step 2. Regulatory personnel may be needed to obtain agreement on the selected site for the replacement wetland.

- Step 3. Regulatory personnel may be needed to obtain agreement on the wetland replacement conceptual design.
- Step 5. Regulatory personnel may be needed to obtain agreement on all technical aspects of the wetland replacement project.
- Step 8. Regulatory personnel may be needed to obtain final regulatory approval of the successful replacement wetland.

Project sponsors must be aware that, at many locations around the United States, federal or state regulatory agency approval or concurrence may be required before project sponsors can advance to the next applicable WRP step. In other cases, approval may not be required or mandated by federal, state, or local regulations. However, coordination with regulatory and resource agencies may yield important information useful to site selection, design, and so forth.

PROJECT REVIEW AND MANAGEMENT TEAM

Project sponsors may want to establish a project review and management team early in the project to facilitate project planning, coordination, and implementation. Generally, the responsibilities of the team may include selecting project technical team members, preparing a work or project plan, initiating and maintaining coordination with regulatory agencies, conducting quality control audits of plans and specifications consistent with standard engineering practice, tracking project costs, tracking and maintaining project schedule deadlines, and ensuring that applicable steps in the WRP are completed to the satisfaction of all stakeholders (including the regulatory agencies) before moving to the next step. The research team recommends that a project review and management team be established early in the WRP (i.e., at or prior to Step 1).

DEFINING WETLAND SUCCESS

The research team found that defining wetland replacement success has been both difficult and controversial. Many definitions have been proposed over the past several years. The lack of consensus on a definition is due in part to the fact that initially many wetland replacement projects were completed without a clear set of goals and objectives. Consequently, it is difficult to assess whether or not the wetland is successful, because there is no measure of success against which to compare the wetland replacement other than by a comparative evaluation with other natural wetlands of similar type in the region. Often the definition of success varies from region to region because of differing experience with specific wetland types and state and local regulations. Finally, the controversy also stems from who is asking the question.

One perspective holds that a wetland replacement project should be considered successful if it persists over time (as stipulated in the permit) in comparing favorably with its plans and specifications (within a specified and agreed-upon range of tolerances that consider natural variability and natural succession). Another is that for any wetland replacement to be considered successful, it must replicate completely the chemical, physical, and biological functions and system structure of the natural wetland it is replacing. Still others have stated that a replacement project is considered successful if it complies with permit requirements or if the project was actually constructed. Finally, others believe that success must be defined in terms of the project's performance goals, thereby defining success on the basis of local wetland resource needs and performance criteria.

The research team initially recommended a definition that reflected the team's own experience, the results of the research project, and the technical orientation of the *Guidelines* themselves. The team's initial definition held that a wetland replacement is considered successful if it conforms over time with the as-built plans, provided there are also some allowances for natural variability and succession. In proposing this definition, the research team recognized that fundamental to the definition are the requirements that a project sponsor must establish as a goal the replacement of lost wetland functions and must prepare technically sound plans and specifications; the wetland then must be constructed according to those plans and specifications. Also fundamental was that postconstruction monitoring and maintenance may be required to ensure success. Project Sponsors who follow the research team's recommended WRP in the *Guidelines* can overcome many of the current problems with wetland replacement which, in turn, will lead to an increase in the number of successful wetland replacement projects.

This definition was not universally accepted by the research panel, because it did not conform to the federal government policy, which holds that success must be defined in terms of whether or not the project provides for the replacement of chemical, physical, and biological functions of wetlands. According to this policy, a wetland replacement project is successful when this broad objective is achieved. Although the research team understands the need to achieve this objective, this objective can be difficult to accomplish. The definition can lead to misinterpretation and disagreement between regulatory agencies and project sponsors about exactly when this objective is achieved and what criteria should be used to measure success. The team's definition of success was thought to overcome these problems within the current limits of understanding of how to restore or replicate wetlands.

In consideration of national policy stating that the objective of mitigation is to provide for the replacement of chemical, physical, and biological functions of wetlands or other aquatic resources unavoidably lost as a result of authorized impacts, the research team now considers a wetland replacement to be successful when this objective is achieved. Ideally, if mitigation plans are properly developed following the WRP, they will provide for the objective within the limits of the technical experience base, and, if a wetland replacement project is established in accordance with these plans, the project will be a success. Therefore, from the research team's perspective, the project must address the design and construction specifications for the replacement site and a continuing program of monitoring and site management that will ensure that the replacement goals and objectives of the wetland replacement are met as well.

A FINAL INTRODUCTORY WORD ABOUT THE WRP

Although some users of the *Guidelines* may want a highly detailed, fixed protocol for designing replacement wetlands, the research team has avoided such an approach because of the complexity and site-specific nature of designing replacement wetlands. Instead, the team has recommended a WRP to guide project sponsors as they address the specific, sometimes unique requirements of their own projects. As conceived by the research team, the WRP will help project sponsors to develop wetland replacement areas successfully. In so doing, the WRP will help to advance the science of wetland replacement itself.

CHAPTER 1

ASSESSING WETLAND FUNCTIONS AND SETTING GOALS AND OBJECTIVES

1.1 DECISION FOR WETLAND REPLACEMENT

The wetland replacement process (WRP) is initiated because of various wetland regulations and policies that may have different requirements (Appendixes A and B). Usually, project sponsors must submit, under the Section 404 permit process, either a permit application or a predischarge notification requiring regulatory review and coordination. States with state wetland regulations may have a joint permit application agreement with the U.S. Army Corps of Engineers (COE) for Section 404. Precoordination of proposed projects with regulatory agencies before submittal of permits often plays an important role in resolving problems. Procedurally, Section 404 permit guidelines require that the sponsors must first explore practicable alternatives that avoid or minimize wetland impacts; however, if wetland impacts are unavoidable, reviewers must determine what impact the project will have on the capacity of the wetland to perform functions and to provide values. A wetland assessment technique may be employed at this stage to do the following:

- Identify functions and values provided by the wetland,
- Evaluate potential impacts on the wetland's capacity to perform functions and provide values, and
- Compare the relative impacts of alternative project plans.

Using the results of the wetland assessment and other project information, the project reviewers and the project sponsor may suggest measures to reduce wetland impacts further. At some point in the precoordination or permit review process, a decision will be made to (1) issue or not issue the permit on the project as proposed, (2) issue the permit with changes to the project, or (3) deny the permit, depending on the project impacts and availability of mitigation. That decision starts the WRP with Step 1. The wetland functional assessment made as part of the WRP is distinct from previous assessments and is narrowly focused on the wetland to be impacted and data requirements for designing the replacement wetland.

1.2 WETLAND FUNCTIONS AND VALUES

Wetlands are legally protected because of the functions they perform and the perceived value these functions provide to society. Although the terms "function" and "value" are often used interchangeably in the literature, the trend is to distinguish between them. In the *Guidelines*, the research team uses the following definitions:

- Wetland functions. These are the physical, chemical, and biological processes that can be attributed to a wetland ecosystem.
- Wetland values. These are the goods and services that benefit human needs when wetlands perform their functions.

Table 1 lists some of the functions that wetlands provide.

Although there is no standard procedure for reviewers and other interested parties to use to determine which functions and values should be evaluated in the wetland to be impacted, they can base their decisions on one or more of the following:

- Results of site-specific research,
- Literature on comparable wetland ecosystems,
- Professional opinion,
- The results of an objective wetland assessment technique that identifies applicable functions and values, and
- Information gathered during the permit review process (e.g., a wetland site provides critical habitat for endangered species, contains an archeological site, holds aesthetic values, or serves for education and research).

At a minimum, reviewers should address the major functions—such as water quality, fish and wildlife habitat, and sediment stabilization; however, the research team recommends that reviewers examine a comprehensive list of functions (e.g., Table 1) to ensure that they have evaluated most of the functions before establishing specific function replacement goals.

1.3 SELECTION OF A TOOL FOR DATA COLLECTION

1.3.1 Background

The accurate assessment of wetland functions and values is fundamental to the WRP. Reviewers can assess wetland functions and values by using professional opinion, conduct-

TABLE 1 Wetland functions

A.	**Flood conveyance**—Riverine wetlands and adjacent flood plain lands often form natural flood ways that convey flood waters from upstream to downstream points.
B.	**Barriers to waves and erosion**—Coastal wetlands and those inland wetlands adjoining larger lakes and rivers reduce the impact of storm tides and waves before they reach upland areas.
C.	**Flood storage**—Inland wetlands may store water during floods and slowly release it to downstream areas, lowering flood peaks.
D.	**Sediment control**—Wetlands reduce flood flows and the velocity of flood waters, reducing erosion and causing flood waters to release sediment.
E.	**Fish and shellfish**—Wetlands are important spawning and nursery areas and provide sources of nutrients for commercial and recreational fish and shellfish industries, particularly in coastal areas.
F.	**Habitat for waterfowl and other wildlife**—Both coastal and inland wetlands provide essential breeding, nesting, feeding, and predator escape habitats for many forms of waterfowl, other birds, mammals, and reptiles.
G.	**Habitat for rare and endangered species**—Almost 35 percent of all rare and endangered animal species are either located in wetland areas or are dependent on them, although wetlands constitute only about 5 percent of the nation's lands.
H.	**Recreation**—Wetlands serve as recreation sites for fishing, hunting, and observing wildlife.
I.	**Water supply**—Wetlands are increasingly important as a source of ground and surface water with the growth of urban centers and dwindling ground and surface water supplies.
J.	**Food production**—Because of their high natural productivity, both tidal and inland wetlands have unrealized food production potential for harvesting of marsh vegetation and aquaculture.
K.	**Timber production**—Under proper management, forested wetlands are an important source of timber, despite the physical problems of timber removal.
L.	**Historic, archaeological values**—Some wetlands are of archaeological interest. Indian settlements were located in coastal and inland wetlands, which served as sources of fish and shellfish.
M.	**Education and research**—Tidal, coastal, and inland wetlands provide educational opportunities for observation and scientific study.
N.	**Open space and aesthetic values**—Both tidal and inland wetlands are areas of great diversity and beauty and provide open space for recreational and visual enjoyment.
O.	**Water quality**—Wetlands contribute to water quality by removing excess nutrients and many chemical contaminants. They are sometimes used in tertiary treatment of wastewater.

ing detailed field studies (i.e., the collection and interpretation of raw data), using a wetland assessment technique, or combinations thereof. In most cases, extensive field studies are unfeasible because of their cost and the time constraints of the permit review process itself. Therefore, the typical assessment combines professional opinion and the results of a wetland evaluation technique.

Functional assessment usually requires the use of indicators that are observable or measurable variables so closely associated with particular wetland functions that their presence or magnitude is verification of the existence or level of a function. To be useful, indicators need to be sensitive enough to determine functional performance within the time and cost constraints of budgets and impacts associated with their observation and measurement. Measures of structure are readily available and are often used as indicators of function. Common examples are species occurrence and species diversity (Kentula et al., 1992).

The reviewers may decide that an assessment by professional evaluation is appropriate. In this case, the professional(s) should prepare a written assessment of the wetland to be impacted and then be available for consultation during later WRP steps, such as site selection, evaluation of the plans for the replacement wetland, and monitoring and reporting.

If the reviewers are not satisfied with available information or have specific concerns on which they find no data, they may require the collection and interpretation of raw data. However, the research team discourages general descriptive surveys unless they provide specific information on function performance (e.g., nesting bird counts might be used to illustrate wildlife habitat use). Any data collected to define how efficiently a wetland performs a function should follow a carefully planned experimental design. Time and resources should only be allocated to studies designed to answer specific questions. When feasible, the study should generate data that are suitable for statistical analysis.

Federal and state agencies, academia, and consulting firms have developed a wide variety of wetlands assessment techniques. Some techniques focus narrowly on one function or one wetland type, while others assess several wetland functions on a national scale (Table 2). The choice of approach depends on several factors. If the replacement wetland area is relatively small, the available wetland assessment techniques prove inadequate, or both, then the assessment may rest on professional opinion. In other cases, regulations or agency policy may require the use of a particular wetland assessment technique. In still other cases, a technique with national application may be the preferred tool. If a satisfactory technique is available for a specific geographic area, it may be more appropriate than a broadly based assessment. A comprehensive technique that evaluates only one function, such as the Habitat Evaluation Procedure (HEP) (U.S. Fish and Wildlife Service [FWS], 1980), may apply in cases where several functions may already have been evaluated in detailed studies.

Another assessment procedure that has been used is Wetland Evaluation Technique (WET) 2.0 (Adamus et al., 1987). This procedure qualitatively assesses 11 functions and values. WET 2.0 is expected to be replaced by the COE within the next few years with a newer procedure based on Brinson's wetland hydrogeomorphic classification system for wetlands (Brinson, 1993). The Hydrogeomorphic (HGM) Approach (Smith et al., 1995; Brinson et al., 1995) is undergoing development of regional models at selected locations in the United States. Development and testing of the regional models are expected to continue for several years; therefore, HGM may not be fully operational for several years at some locations in the United States.

Several publications provide a review of different wetland assessment techniques (e.g., Lonard et al., 1981 and 1984; U.S. Environmental Protection Agency [EPA], 1984 and 1990). Information includes abstracts of each methodology, comments on the thoroughness of individual techniques for specific functions, personnel expertise needed, summaries and comparison of wetland functions, applicability to a geographic area, data requirements, and the relative flexibility of the assessment technique.

Table 2 lists some of the available techniques, their application to wetland types or regions, and the functions they analyze. This list is not comprehensive—many other regional methods are under development or have recently been released (Minnesota Board of Water and Soil Resources, 1995; U.S. COE, 1995)—and references cited represent some of the more frequently used assessment techniques; however, any decision about which one to use must be made on an individual replacement-project basis because reviewers and others may need to modify the technique to ensure that it applies to the WRP.

1.3.2 Applicability of Existing Wetland Assessment Techniques to the WRP

Although several wetland assessment techniques are available, no one technique can satisfy the needs of all replacement projects. The following questions should be asked when choosing an assessment technique:

- What will be the cost in time and dollars to use a given assessment technique? Is it a rapid, low-cost technique?
- Will this technique address the functions and values of concern to this project?
- Is the technique applicable to the region?

A more basic concern is whether or not a given technique is even appropriate for the WRP. The research shows that techniques may not apply because of the following five major technical problems:

- The use of arbitrary threshold values,
- The use of opportunity elements in estimating function performance,
- A format that is difficult to use in the WRP,
- The exclusion of other elements important to wetland replacement design, and
- Not enough sensitivity to detect differences between wetlands.

Reviewers should examine carefully any wetland assessment technique under consideration for its appropriateness for the WRP. They may need to modify existing procedures for the following reasons:

- Threshold Values: Assessment techniques use threshold values to define the limits of conditions that contribute to and determine the wetland's capacity to perform a function. Many relationships between structure and function in a wetland can be expressed as valid qualitative principles. For example, one well-established principle is that shorelines with a broad vegetated fringe have a greater potential for protecting the shorelines than shore areas without a fringe or with only a sparse one. This is an important relationship. In this case, how-

TABLE 2 List of some available wetland assessment techniques and their attributes (included are those techniques that Lonard et al. (1981) considered applicable to mitigation. Post-1981 techniques are also identified.)

Method	Functions[1]	Application	disciplinary Team?	Quick Answers?	Endproduct
Adamus et al., 1987	H, Hyd, R, - ,Her[2]	Widespread application	No	Yes	Qualitative probability ratings of high, moderate, or low: 11 functions and values
Adamus et al., 1990	H, Hyd, R, - , Her	Developed for bottomland hardwoods	No	Yes	Qualitative probability ratings of high, moderate, or low: 10 functions
Ammann et al., 1986	H, Hyd, R, A/S, Her	Developed for Connecticut; Target user: state and municipal inland agencies; Coastal wetlands not addressed; Must be modified for widespread application	No	Yes	Numerical ranking of several wetlands, based on numerical rating of 13 functional values
Ammann and Stone, 1991	H, Hyd, R, - , Her	Developed for New Hampshire; Target user: state and municipal inland agencies; Coastal wetlands not addressed; Must be modified for widespread application	No	Yes	Numerical ranking of several wetlands, based on numerical rating of 14 functional values
Bartoldus et al., 1994	H, - , - , - , Her	Developed for planned wetlands and other applications Widespread application with instruction to modify as needed	No	Yes	Numerical ratings for 6 functions
Bradshaw, 1991	H, Hyd, R, - , Her	Developed for nontidal wetlands in coastal plain of Virginia; Must be modified for widespread application	No	Yes	Qualitative probability ratings of high, moderate, or low; 8 functions
Cable et al., 1989	H, - , - , - , -	Widespread application	No	Relatively	Numerical rating of relative habitat quality
Cook et al., 1993	H, - , R, - , Her	Developed for New Hampshire coastal wetlands; Must be modified for widespread application	No	Yes	Numerical ratings for 9 functions

[1] H = Habitat; Hyd = Hydrology; R = Recreation; A/S = Agriculture/Silvaculture; Her = Heritage
[2] Dashes (",-,") in this column indicate what functions the instrument does not measure

TABLE 2 List of some available wetland assessment techniques and their attributes (included are those techniques that Lonard et al. (1981) considered applicable to mitigation. Post-1981 techniques are also identified.) *(continued)*

Method	Functions[1]	Application	Require Inter-disciplinary Team?	Quick Answers?	Endproduct
Environmental Working Group, 1994	H, - , - , - , -	Developed for Louisiana coastal wetlands to prioritize project proposals for wetland enhancement; Must be modified for widespread application	No	Yes	Numerical ratings of relative habitat value
Euler et al., 1984	H, Hyd, R, - , Her[2]	Developed for wetlands of Ontario	No	Yes	Numerical ratings
Golet, 1973	H, - , - , - , -	Developed for Massachusetts; Coastal wetlands not addressed; Must be modified for use outside the northeast	No	Relatively	Numerical rating of relative wildlife value
Hollands & McGee, 1986	H, Hyd, R, - , Her	Developed for Massachusetts; Coastal wetlands not addressed; Must be modified for use outside the northeast	No	Yes	Numerical ratings for 10 functions
Larson, 1976	H, Hyd, - , - , Her	Developed for Massachusetts; Coastal wetlands not addressed; Must be modified for use outside the northeast	Yes, under certain conditions	Yes	Numerical rating that includes values for a number of wetland functions
NCDEHNR, 1995	H, Hyd, R, - , -	Developed for North Carolina freshwater wetlands; Must be modified for widespread application	No	Yes	Numerical ranking for several wetlands based on numerical ratings of 6 functions
Roth et al., 1993	H, Hyd, R, - , Her	Developed for freshwater wetlands in Oregon; Must be modified for widespread application	No	Yes	Qualitative ratings indicating whether the wetland provides or has/does not have the potential to provide each of 9 functions
U.S. COE & Minnesota Environmental Quality Board, 1988	H, - , - , - , Her	Developed for North Central U.S.; Coastal wetlands not addressed; Must be modified for widespread application	No	Yes	Numerical and qualitative ratings, depending on function
U.S. FWS, 1980	H, - , - , - , -	Widespread application	No, but encouraged	Relatively	A matrix of relative quality values that may be used to give numerical comparisons, predictions, and baseline assessments; tables and forms

H = Habitat; Hyd = Hydrology; R = Recreation; A/S = Agriculture/Silvaculture; Her = Heritage
Dashes (",-,") in this column indicate what functions the instrument does not measure

ever, it is difficult to establish what constitutes the "best" (or threshold) width to prevent shoreline erosion. Different assessment techniques use different threshold widths: Ammann et al. (1986) uses a wetland width of 10 ft, Adamus et al. (1987) uses 20 ft, and Reppert et al. (1979) uses 600 ft as the threshold width.

Although these thresholds may be appropriate for general impact and alternatives analyses, they have caused problems in the WRP. The problems with these thresholds are as follows:

- In many cases the thresholds were not and cannot be literature-validated. They were included simply as indicators, not absolute measures of function performance.
- These thresholds are erroneously interpreted by some as design criteria for replacement wetland plans.

The design criteria for a replacement area could vary widely, depending on the threshold of the assessment technique employed. Following the example above, the recommended wetland width in each technique varies tremendously (i.e., more than 10 ft or more than 20 ft or more than 600 ft). It is not evident which threshold is most valid from the design perspective.

- Opportunity Elements: Another problem arises in estimating the level of performance for a function when elements describing "effectiveness" (e.g., indicators, factors, predictors, and features) are combined with those describing "opportunity." "Opportunity elements" are those characteristics of a wetland or its surroundings that determine if the opportunity is available for that wetland to perform a function. If the opportunity is absent, the wetland is usually assigned a low score: the assessment technique assumes that the wetland cannot perform the function. Many of the opportunity elements describe conditions that might jeopardize the establishment of a replacement wetland. For example, in some wetland assessment techniques, fetch—exposure of the shoreline to open water and, therefore, potentially high wave energy—is an opportunity element. The assessment tool assumes that the greater the fetch, the greater the opportunity, and the more valuable the wetland is for performing the shoreline bank erosion control function. No upper limit is set on this opportunity; however, the design and site selection phase of the WRP requires a defined upper limit for it nonetheless. It may be impossible to establish a new wetland in conditions where the fetch is too great. By placing greater value on wetlands with the greater opportunity, existing techniques "favor" the natural wetland over the replacement wetland.

  Assessment techniques also often use opportunity elements in evaluating the water quality function (e.g., watershed land use and presence of pollutant sources). In many assessment tools, urban land use represents an opportunity to improve water quality; therefore, urban land use rates a high score when used to calculate the water quality function. These techniques, however, do not allow for limits on this opportunity. A wetland could have a low pollutant-removal efficiency, particularly if it has reached a limit on its capacity to assimilate the high nutrient and toxics levels caused by a current land use. Most existing wetland assessment techniques fail to recognize this key consideration: that the capacity of a natural or replacement wetland to perform a function may be minimal or already exceeded because of existing land use.
- Formats of Existing Wetland Assessment Techniques: In addition to problems with threshold values and combining opportunity and effectiveness elements, the formats of existing wetland assessment techniques do not readily accommodate the review phase of wetland replacement plans, particularly during the design process when evaluators should examine the plan for its potential to achieve the project goals and objectives. Instead, the assessment techniques are generally organized for easy combination of elements to produce some measure of function. But in the design phase of the WRP, the user must work back through the assessment procedure to identify the elements important to each function so that, if needed, the elements can be changed in the plans. Existing technique formats make this process difficult, if not impossible.
- Exclusion of Elements Important to Wetland Replacement Design: Finally, many existing techniques use a minimum number of elements for each function because the techniques are designed for rapid assessment. It is common to see only three to five elements used to assess one function. Other structural, and equally important, elements that can be used in the design of a replacement wetland are excluded from consideration. Such exclusions may result in an adequate general assessment of various wetland functions but may overlook elements critical to determining function in an existing or a replacement wetland.
- Sensitivity: The degree to which a wetland assessment technique detects differences among wetlands is termed "sensitivity." Some wetland assessment techniques are highly sensitive and can indicate subtle differences. In general, the more comprehensive the technique, the more sensitive it is. Most rapid assessment techniques have a relatively low degree of sensitivity, which limits their use for the WRP.

The WRP requires a thorough assessment of wetland functions in order to set specific goals and objectives. If the technique has low sensitivity, then the goals and objectives will reflect this lack of detail. Low sensitivity also becomes more critical as the WRP proceeds to site selection, design, and monitoring. In these later steps, detecting differences is important to determining the potential achievement of stated goals and objectives. If an assessment technique has low sensitivity, it may be unable to detect differences (i.e., increases or decreases in function) between the wetland to be impacted and the replacement wetland represented in the plans.

Users of assessment techniques should recognize that new techniques continue to be developed and that these future techniques also may be suitable for the WRP. The Evaluation for Planned Wetlands (EPW) (Bartoldus et al., 1994) is a rapid assessment technique specifically designed to help project sponsors determine if the goals and objectives of the wetland replacement can be achieved (an overview of the EPW appears in Appendix J).

1.4 SETTING GOALS AND OBJECTIVES FOR THE REPLACEMENT WETLAND

TWO KEY REPLACEMENT ISSUES

Sometimes it may be beneficial to provide a replacement wetland that is of a different type or that has a different vegetative community than the wetland to be impacted or both.

Emphasizing one function may reduce the wetland's capacity to perform another function.

1.4.1 Setting Goals and Objectives

Once the assessment has been performed on the wetland to be impacted, the project staff should set wetland function replacement goals and objectives to assist with Steps 2, 3, and 5 of the WRP. The site selected for the wetland replacement (Step 2) and the wetland replacement design (Steps 3 and 5) must be able to meet the selected goals and objectives.

Project staff may establish goals and objectives of the wetland replacement as follows:

- Replace the same type of wetland as that to be impacted (Appendix A, in-kind mitigation),
- Replace the impacted wetland with a different wetland type (Appendix A, out-of-kind mitigation),
- Create the same vegetative community as that found in the wetland to be impacted,
- Create a different vegetative community from that found in the wetland to be impacted,
- Duplicate the functions at the performance levels recorded in the wetland to be impacted,
- Increase or decrease functions to levels different from those recorded for the wetland to be impacted, and
- Add one or several functions that are not recorded for the wetland to be impacted.

Out-of-kind mitigation (Appendix A) may be acceptable under well-documented conditions, with consensus approval from regulatory agencies. The WRP may be applied to accommodate out-of-kind replacement projects by identifying specific goals and objectives that best fit the available wetland replacement site. Examples A through C illustrate out-of-kind replacement.

1.4.2 Use of Reference Wetlands

On the basis of its experience in the field, the research team believes that reference wetlands can be used as comparative guides in designing replacement areas and in estab-

EXAMPLES WHERE GOALS AND OBJECTIVES SUPPLY NEEDED FUNCTIONS RATHER THAN REPLACING THOSE LOST IN THE WETLAND TO BE IMPACTED

EXAMPLE A: The wetland to be impacted provides wildlife and bird-nesting habitat; however, water quality and the lack of fisheries habitat is a major problem in the water body associated with the wetland replacement site. Consequently, it would be most desirable for the wetland replacement to improve on the fisheries habitat.

EXAMPLE B: The wetland to be impacted is at an airport expansion location and provides important waterfowl and shorebird functions. The wetland replacement will be designed to minimize its value to avifauna in order to reduce the potential for bird-aircraft collisions, while providing the needed stormwater water quality management function for the airport expansion.

EXAMPLE C: The wetland to be impacted provides a strong water quality enhancement function; however, the water quality is good at the wetland replacement site. What is needed is a different type of wetland from that to be impacted (i.e., higher elevation and with different vegetation) that would provide a rookery for herons and Least terns.

lishing replacement goals and objectives for them. For in-kind mitigation projects, the impacted wetland itself becomes the reference for the goals and objectives regarding function. If out-of-kind mitigation is the preferred option, or if the impacted wetland has been filled or impacted before assessment, a reference wetland may not only be useful but necessary in establishing goals and objectives for the replacement site. Replication of the attributes of the reference wetland should be the goals and objectives of the replacement wetland. The level of functions provided by the reference wetland also can be used as the standard for measuring the level of functions attainable within the replacement area's watershed or region. Chapter 4, Section 4.2, identifies other uses of reference wetlands in the WRP.

Selecting an appropriate reference site depends on the desired functions to be replaced. Generally, coordination with regulatory agencies will help project sponsors to identify the desired functions the replacement wetland will provide. Once identified, the sponsors then will need to search for a reference site that provides the identified functions. The reference site should be within the same watershed as the replacement site and should be similar in hydroperiod and vegetation. To find a suitable reference site, project sponsors may review wetland maps, such as National Wetland Inventory (NWI) maps, state inventory maps, or recent aerial photography of the area. Generally, coordination with regulatory agencies is necessary during this process to reach a consensus about an appropriate reference site.

CHAPTER 2

SELECTING THE SITE

2.1 INTRODUCTION

Site selection involves identifying and screening candidate wetland replacement sites and then choosing the optimum one for wetland replacement. During Step 2 in the WRP, project sponsors should examine any factors that could exclude a potential site from use for the wetland replacement. The research team recommends that project sponsors should not prepare conceptual plans (Step 3), collect additional information (Step 4), or prepare final plans and specifications (Step 5) until they verify that the candidate site is feasible. Table 3 lists procedures and evaluations to select possible replacement sites; Table 4 identifies characteristics that make a candidate site unsuitable, difficult, or expensive for use in wetland replacement. This site selection step should be coordinated thoroughly with other agencies involved in the mitigation process. In some cases at this stage, it may be beneficial to coordinate with community officials about the proposed replacement project. Through this process, project sponsors often identify opportunities for mitigation that meet existing regional wetland management goals.

Ideally, the replacement area should be on site, directly next to the impacted wetland, and near or within the existing or proposed rights of way (Appendixes A and B). Using these criteria can reduce or eliminate the time and effort needed to identify candidate sites.

Unfortunately, on-site replacement areas are not always available, desirable, or technically feasible, given certain site-specific considerations, such as the following:

- Potential water quality problems from highway stormwater runoff (e.g., roadway deicing),
- Incompatible adjacent land use and zoning,
- Inadequate space for the size of the wetland replacement or for accommodating existing buffer zone requirements,
- Lack of adequate hydrology to support the replacement wetland,
- State and local performance standards and regulations governing wetland replacement,
- Cost-effectiveness of constructing the wetland next to the impacted site,
- Goals and objectives of the wetland replacement, and
- Postconstruction institutional maintenance considerations.

If on-site areas are not available, then project staff must identify an off-site location for the replacement wetland (Appendixes A and B). The first priority is a replacement site in the same watershed. From a practical and regulatory perspective, a "watershed" is defined as the area contained within a drainage divide above a specified point on a stream. Watersheds range in size from very small (acres) to very large (hundreds or thousands of square miles). Whenever possible, project staff should locate the replacement wetland within the same watershed and within the same vicinity as the wetland being replaced.

For example, if water bodies, such as bays or lakes, were affected, then locating the replacement wetland within the vicinity of the impact area would mean placing it in the tidal creek system where the bay impact occurred or in the same area of lake shore where the lake impact occurred.

If a suitable site within the same watershed or vicinity cannot be found, then sites should be identified in adjacent watersheds or other areas acceptable to the regulatory agencies. If the project requires multiple replacement sites—as on larger corridor projects—project staff may need to examine several watersheds for candidate replacement areas.

The site selection process has the following two stages:

- Site screening—identifying possible candidate sites on the basis of published information and selection criteria and
- Site selection—evaluating sites in more detail to select the recommended site.

To avoid potentially expensive mistakes, project personnel must investigate, during site selection, characteristics that may make the area unsuitable for wetland replacement.

TABLE 3 Procedures used in site selection

Not all procedures and evaluations discussed in this chapter are necessary for all potential wetland replacement sites. This table identifies factors that are examined always, usually, or rarely.

Procedure or Factor (Chapter)	Frequency of examination: Always	Usually	Rarely
Office-level evaluation (2.3)	✓		
"Windshield level" assessment (2.4)	✓		
Field assessments (2.5)	✓		
Verifying satisfaction of goals and objectives (2.5.1)	✓		
Through use of evaluation models (e.g., HEP, EPW)		✓	
Through use of design guidelines (e.g., HEP, EPW)		✓	
Biological benchmark data (2.5.2)		✓	
Hydrologic verification (2.5.3)			
Through field verification	✓		
Through field monitoring			✓
Through hydrologic modeling			✓
Through hydrologic calculations (Appendix E)		✓	
Soils analysis (2.5.4)			
Soil samples at proposed design depths	✓		
Soil infiltration tests			✓
Landfill survey			✓
Chemical sampling			✓
Water quality analysis (2.5.5)			
General field evaluation for potential contaminant sources	✓		
Chemical sampling			✓
Sediment loading models			✓

The level of effort required to complete the site screening and site selection will vary for many reasons, including the following:

- The specific goals and objectives of the wetland replacement, including functions to be replaced;
- The type and number of wetlands impacted;
- The watershed of the replacement site;
- The total acreage to be replaced;
- The available land on which to build a wetland replacement; and
- The applicability of federal, state, and local regulations and permit requirements (e.g., Section 106 of the National Historic Preservation Act and the Federal Endangered Species Act).

Table 3 summarizes the procedures to conduct and the factors to consider that may be necessary in the site selection process. Table 3 also indicates which procedures must always be implemented versus those necessary only in rare situations.

TABLE 3 Procedures used in site selection *(continued)*

Procedure or Factor (Chapter)	Frequency of examination: Always	Usually	Rarely
Acreage (2.5.6)			
Wetland delineation (2.5.6)		✓	
Topographic survey (2.5.6)	✓		
Determination of buffer requirements (2.5.6)	✓		
Landscape context (2.5.7)			
General surrounding land use survey (2.5.7)	✓		
Shade survey (2.5.7)		✓	
Construction access determination (2.5.7)	✓		
Human access determination (2.5.7)		✓	
Invasive vegetation and problem animals (2.5.7)	✓		
Landscape ecology context (2.5.7)		✓	
General archaeological and historical site surveys (2.5.7)	✓		
Institutional constraints (e.g., zoning and water rights; 2.5.7)	✓		
Hazardous waste and substances investigations (2.5.7)		✓	
Threatened and Endangered Species Assessment (2.5.7)		✓	
Construction feasibility and cost-effectiveness (2.5.8)	✓		

2.2 GENERAL CONSIDERATIONS

Defining the goals and objectives of the wetland replacement is important. Once established, project staff use them to identify site screening and site selection criteria. Project sponsors need to be aware that a specific site-screening list of concerns and characteristics may need to be developed for different mitigation goals and objectives. If the project personnel set only very general goals and objectives at the outset, they should still develop specific site screening criteria during this stage of the WRP.

A general misconception about site selection is that an existing wetland can always be enlarged by excavating an adjacent upland area to create the wetland replacement. In this case, project staff might assume that because the existing wetland has the proper grades and appropriate hydrology, enlarging it will produce a successful wetland replacement. Although this approach applies to tidal wetlands, because ocean waters are essentially unlimited in available volume, the approach does not apply to nontidal wetlands. The hydrology that supports a 20-acre wetland may be insufficient to supply a 40-acre wetland. Consequently, enlarging a 20-acre wetland to 40 acres as a replacement project could jeopardize the original and, now, the expanded replacement wetland as well.

Considerations for enlarging existing nontidal wetlands as replacement sites include verifying that the existing hydrology can support the expanded wetland. This verification may entail stream monitoring, groundwater testing, watershed analysis and calculations, other hydrologic determinations, or combinations thereof (Section 2.5.3).

It is not valid to assume that any available piece of land can be engineered to support a wetland community. Surrounding land use, topography, hydrology, soils, and water quality can significantly influence the technical and eco-

TABLE 4 Site characteristics that may make a site unsuitable, difficult, or expensive for use in wetland replacement

Site Characteristic	Makes the site unsuitable	Makes the site difficult or expensive to use
Can be identified at the office level		
Obviously unsuitable hydrology	■	
Incompatible land use obvious on the aerial map	■	
Total acreage needed for the project is not available	■	
Site is mapped as critical habitat for endangered species	■	
Topographic maps indicate a large topographic relief	■	■
Site is an existing wetland		■
Can be identified during windshield-level assessment		
Obviously unsuitable hydrology	■	
Incompatible surrounding land use not evident on aerials	■	
Large topographic relief	■	■
Biological benchmarks absent		■
Site is an existing wetland		■
Excessive shade		■
Lack of existing data (e.g., stream gauge data)		■
Access is a problem		■
Existing rights of way that impact the design		■
Physical features that impact the design (e.g., rock outcrops)		■
Can be identified during analysis of selected alternative sites		
Insufficient hydrology	■	
Water quality problems	■	■
Site contamination (hazardous waste/substances)	■	■
Subsoil at the design elevation is unsuitable	■	■
Privately owned land with an unwilling seller		■
Archaeological or historical sites are present		■
Problem animals or invasive plant species are present		■

GOALS AND OBJECTIVES

The project staff should define clearly the goals and objectives for the replacement wetland before beginning to select the site (Chapter 1.4).

Do not assume that an existing wetland can be enlarged to accommodate the acreage needed for the replacement wetland.

nomic feasibility, as well as the long-term success of a replacement project.

Project staff also must consider regulatory constraints when selecting a site. For example, permit conditions may mandate that a replacement area be in the same watershed as the impacted wetland site. Regulators are hesitant to allow mature forests or valuable fish and wildlife habitats to be destroyed to create wetlands. Appendixes A and B provide a more detailed overview of technical and regulatory constraints that may affect site selection.

2.3 INFORMATION SOURCES FOR SITE SCREENING

Site selection should begin as an office-level survey of existing information. Important data sources that can be used to identify candidate sites include the following:

- United States Geological Survey (USGS) Maps: These maps, which have scales from 1:24,000 to 1:2,000,000 and contour intervals of 10 to 150 ft (depending on the map scale and topographic relief of the region), are useful in assessing the watershed area and determining its general topography. Recently updated versions can help determine general land-use patterns and possible access points to potential replacement sites.
- United States FWS NWI Maps: NWI maps are at a scale of 1:24,000, and can be obtained as mylar overlays to USGS maps or as prints. These maps show wetland areas that are detectable from aerial photography. Although varying in accuracy and coverage (i.e., they are not available for some regions of the United States), they can be useful in identifying the location of existing wetlands. The mylar maps can be used with soils data, aerial photography, and other information to identify adjacent tracts as potential replacement sites.

  Some of the NWI maps are generated from aerial photography with the wetland areas superimposed onto the photographs. If photography is recent, the maps can be used to assess land-use patterns in the region, such as agricultural fields next to wetlands that may be suitable wetland replacement sites.
- United States Department of Agriculture Soil Conservation Service (SCS) Soil Surveys: Completed for most of the United States, soil surveys identify major soil types, usually by county, and some of the associated slope characteristics. The soil types generally are drawn onto aerial photographs. In many parts of the country, hydric soils lists also have been drafted. Generally, soil surveys can be used to assess the soil types and characteristics of potential wetland replacement sites and to identify hydric soils in the watershed. They also may show drainage channels in much greater detail than USGS topographical maps, including nonperennial streams not shown on the USGS maps. As with NWI maps, recent SCS aerial photographs or revised surveys can be helpful in identifying land-use patterns and in pinpointing agricultural fields with hydric soils that may serve as potential replacement sites.
- Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs): These maps delineate the 100-year flood elevations for most regions of the country. They have limited use in situating wetland replacement projects but may have some value in identifying flood-prone areas under consideration as replacement sites. FEMA also has flood studies for certain watersheds; where available, they may help in estimating flood flows and elevations.
- Aerial Photography: Aerial photographs are particularly useful in identifying unmapped wetlands, confirming historic and recent land use, identifying general drainage characteristics, and confirming the location of NWI-mapped wetlands. Most state highway agencies (SHAs) have either their own aerial photograph library or recent aerial photographs for specific projects.
- Tax Maps: Tax maps help identify the acreage of potential sites, and they indicate which properties are publicly and privately owned. Publicly owned sites feasible as replacement areas may be substantially less costly to acquire than privately owned property. Tax maps also help determine whom to contact for access to private lands if a site visit is necessary.
- Local Studies: In many instances, state or local governmental bodies will have completed engineering, land

Do not assume that a replacement wetland can be successfully constructed on any available upland site.

use, and environmental studies that can be useful information sources. These studies may include

- Natural resource area surveys,
- Flood-plain studies,
- Groundwater studies and existing well log data,
- Surface water quality studies,
- Land use surveys,
- Wetland inventories,
- Inventories of landfill sites (active and abandoned),
- State and federal inventories of hazardous waste sites, and
- Critical habitat for threatened and endangered species.

Using these sources, project personnel can identify potential sites and rule out others immediately. Table 4 summarizes some characteristics that will, at this level, help to identify sites that would be difficult or expensive to work with or to identify sites that should be eliminated from consideration for wetland replacement.

2.4 SCREENING AND SELECTION OF ALTERNATIVE SITES

On the basis of their office-level review of available data, project staff should identify several areas as potential sites for the replacement wetland. They should make their evaluations quickly using a "windshield-level" assessment (i.e., they should visit the potential replacement areas briefly to learn if there are any obvious site-specific conditions that would preclude the site from use). Such conditions include the following:

- Changes in land use (e.g., farm land that is now a housing development);
- Insufficient hydrology;
- Clearly too much excavation required for the project to be economically feasible;
- A site reverting to a forested or wetland habitat type;
- Potential hazardous waste;
- Utilities present (e.g., storm sewers, waterlines, and power transmission lines) not shown on available maps; and
- Obvious water quality issues (e.g., sedimentation or erosion problems upstream of the site).

This preliminary screening should narrow the list to sites that warrant more thorough project staff assessment.

2.5 ANALYSIS OF SELECTED ALTERNATIVE SITES

Final site selection requires that project staff conduct a more detailed investigation of site characteristics to assess the feasibility of the site for supporting the replacement wetland. Generally, the primary criteria for site selection are as follows:

- The goals and objectives of the wetland replacement can be met.
- Appropriate biological benchmarks are present.
- Hydrology can be provided to support the replacement wetland.
- Soils will support the establishment of the wetland.
- Water quality will not prevent the establishment of the replacement wetland.
- Sufficient acreage exists to support all aspects of the wetland replacement site.
- The landscape surrounding the site will not prevent wetland establishment.
- Construction is feasible and cost-effective.

These criteria are described in the following sections.

2.5.1 Goals and Objectives

As a first step in the site selection process, project staff must determine the type of wetland to be created (Appendix D) and the functions that are to be replaced. After the goals and objectives of the project have been established, project staff must determine whether they can be realized at the potential wetland replacement site. Several models, both single- and multi-parameter, have been designed to evaluate wetland functions. The research team believes that none of the multi-parameter models has proven satisfactory in the WRP (Chapter 1), although in tests completed to date along the East Coast, EPW has proven valuable and may prove useful for other areas of the country, as is or with modification to fit local conditions. The HEP (U.S. FWS, 1980) has proven to be a useful single-parameter model for wildlife. Other single-parameter and multi-parameter guidelines that can be helpful in the site selection process include Hunter (1991) for fisheries habitat, Kress (1985) for bird habitat, Hammer (1989) and Schueler (1992) for water quality, and Marble (1990) for 11 functions and values.

Although guidelines may be helpful in determining whether a candidate site can meet the goals and objectives

Project staff should never rely on wetland evaluation models as a substitute for on-site evaluation during site selection.

developed in Step 1 of the WRP, they do not replace professional experience and expertise in making the final site selection.

2.5.2 Biological Benchmarks

A wetland biological benchmark is one or more plant species at a given elevation that, for decades or longer, has been associated with and supported by hydrologic conditions adjacent to, and proposed for use at, the wetland replacement site. Once the elevation range is known, the area can be graded to reflect the benchmark elevational range and can then be connected hydrologically to the water source. With these tasks completed, the project staff can expect the replacement site to support the same wetland species, or community, as the benchmark species.

Biological benchmarks reflect seasonal water level changes (in lakes, rivers, and streams), tidal elevations (e.g., normal tidal range, spring tidal range, and mean high water [MHW]), and seasonal water salinities. Therefore, depending on the type of wetlands being replaced, the presence of biological benchmarks at the replacement site may eliminate the need for extensive monitoring, or such presence may reduce greatly the amount of site-specific information usually required to confirm hydrologic conditions at the replacement site. There are some restrictions on using biological benchmarks; these are discussed later in this section.

The use of biological benchmark data during site selection and design (Chapter 5) to determine site hydrologic conditions for establishing vegetated wetland elevations has been found to be extremely useful for the following:

- Tidal, emergent wetlands;
- Tidal or nontidal, submerged or floating, aquatic wetlands;
- Nontidal, flood-plain, bottom-land, hardwood wetlands; and
- Nontidal wetlands associated with rivers, perennial and intermittent streams.

The preceding wetland types are all examples of riverine and fringe wetlands, as defined in Appendix E (Table E-8). Such wetlands are associated with permanent surface water bodies that exert a stabilizing influence on hydroperiod, and they permit the establishment and long-term maintenance of species or communities used as biological benchmarks.

If on-site biological data are not available, then biological benchmark data can be collected on adjacent sites that rely on the same hydrology. Project staff can determine the proper elevation on replacement sites most accurately with on-site or adjacent biological benchmarks. Therefore, to determine the correct hydrology, project staff should regard more favorably those potential replacement sites that meet this requirement than those with less reliable information.

Biological benchmarks will not be available for nontidal wetlands driven by groundwater or stormwater (i.e., for basin wetlands, as detailed in Appendix E) unless an existing wetland of this type is being enlarged as a replacement area. In such a case, project staff must confirm that the existing hydrology can support the enlarged wetland.

When collecting biological benchmark data during this step in the WRP, the number of individual elevations required to establish the elevation of the benchmark will depend on site-specific features. More than one biological benchmark will be required if more than one wetland zone is to be established. For example, a nontidal, emergent wetland may have distinct biological benchmarks for the deep zones (more than 1 ft of water), shallow zones (less than 1 ft of water), and occasionally flooded zones (1 to 2 ft above normal pool level). A tidal freshwater wetland may have distinct biological benchmarks for the high marsh, low marsh, and forested wetland zones. At least 10 individual elevations should be taken within each benchmark species or community. Depending on the site and community type, the elevations may be taken at the upper and lower boundaries or randomly. These can then be averaged to obtain a single elevation estimate for the entire area or for each of the upper and lower boundaries. Usually range (maximum and minimum elevations) is important in determining the distribution of depth- or saturation-sensitive species and communities, while a single value is useful for facultative communities.

The recording of biological benchmark elevations during site selection is essential to establish hydrologic conditions and the approximate final grade elevations required at the site to support the desired wetland community. In addition, establishing approximate final grades is important in determining the overall cost feasibility of the proposed site. Project staff also will have to establish approximate grades to assess whether or not the soils at these grades (Appendix F) will support the replacement wetland and how much earthwork and site preparation must be done. Project staff then will use this and other information generated during this step in the WRP to estimate the costs of constructing the replacement wetland at the site.

Project staff should realize that the value of biological benchmarks may be limited in wetland areas subject to certain topographic, geologic, hydrologic, and ecological influences. For example, localized extremes in slope, soil conditions, drainage, and vegetative competition are likely to influence the occurrence and distribution of certain plant species; therefore, project staff must consider these possible effects when collecting biological benchmarks.

2.5.3 Hydrology

The hydrology at the candidate replacement sites is one of the most crucial factors to consider, not only during site selection but throughout the WRP (Appendixes E and G). During site selection, project staff must determine whether sufficient hydrology exists or can be established at the candidate site to support the desired wetland replacement type.

Despite the known importance of hydrology to establishing and maintaining wetlands and the functions they provide, there are no standardized procedures that project staff might use to determine the correct hydrology for the wetland replacement design, although guidelines have been prepared (Pierce, 1993). The potential complexity and variability of wetland hydrology make it very difficult, from an engineering and design perspective, to generalize. Hydrology is a complex issue because wetlands occur at the boundaries between aquatic and terrestrial environments and between groundwater and surface water flow systems. The hydrology that supports the various wetland types repre-sents a continuum of the occurrence, properties, and movement of water on the landscape.

EXAMPLES OF BIOLOGICAL BENCHMARK USES FOR SPECIFIC WETLAND TYPES

EXAMPLE A: Biological benchmarks are useful in creating tidal wetlands. For example, on the East Coast, tidal inundation results in two major vegetative communities—low and high marsh. Local mean high water (MHW) can be estimated by taking the average of the lowest elevations of a healthy, monotypic stand of saltmarsh hay (*Spartina patens*). The biological benchmark elevation established by using *S. patens*, when used in conjunction with the elevations of the biological benchmark low marsh species (e.g., saltmarsh cordgrass [*Spartina alterniflora*]) give the local elevations for the limits of low marsh and the lower limit of the high marsh.

EXAMPLE B: Some plant species can grow in more than one zone in a wetland. For example, saltmarsh cordgrass, a common East Coast tidal marsh plant, exhibits different growth patterns depending on what zone within the marsh it is found. In the low marsh zone where the plant receives daily inundation and draining through tidal action, it grows taller than those individual plants found growing at MHW and above. Therefore, if the goal of the replacement wetland design is to establish a low marsh, biological benchmark information should only be collected in the zone that supports the taller growing vegetation.

EXAMPLE C: Many plant species are facultative (i.e., they can grow in either a wetland or an upland habitat). For example, the red maple (*Acer rubrum*) can be found growing in forested wetlands throughout the north and southeast. Next to these wetlands, the same species can be found growing in the uplands. If red maple is used as one of the biological benchmark species, care must be taken to collect only biological benchmark data from red maples growing in the wetland area and not trees growing in the adjacent uplands. These data always should be augmented with benchmark data collected from plant species found exclusively in the wetland.

EXAMPLE D: Great Lakes wetlands have some unique characteristics. Both runoff and long- and short-period oscillations affect lake water levels. The long-period oscillations are related to volumetric changes. Short-term oscillations result from tilting of the surface water by wind and atmospheric pressure differences. The Great Lakes are also affected by solar and lunar tides, but effects vary from lake to lake. In response to these water level changes, emergent plant communities are known to change from year to year, making it more difficult to use specific species as biological benchmarks unless they are known to have broad tolerances to water-level fluctuations or to have existed in the same location for a long time.

EXAMPLE E: Forested, flood-plain wetlands that are seasonally flooded also can be created using biological benchmarks. The necessary ranges for the flood plain or a certain species within it can be obtained from flood-plain limits and the associated plant communities. Caution must be exercised, however, when using mature woody species as benchmarks. These plants may be relicts reflecting a groundwater or surface water hydrology that may have been modified or that no longer exists. This is particularly the case along many riparian systems in the Midwest where a combination of eroding (deepening) stream beds and a drop in the regional water table has occurred. Under these conditions, additional hydrologic data are necessary.

EXAMPLE F: On many inland tidal bays (e.g., Barnegat Bay, New Jersey), tidal amplitudes cannot be accurately predicted. Lunar and solar tidal amplitudes can be a matter of inches, and the driving force for tidal action is wind. Under these circumstances, biological benchmark information should be used.

Verification of the hydrology is crucial to the success of a wetland replacement project.

HYDROLOGY AND BIOLOGICAL BENCHMARKS

In conjunction with analyzing the hydrology of the site, it is important to collect biological benchmark information (Section 2.5.2); however, biological benchmarks generally are not available for wetlands driven by groundwater or stormwater runoff.

The few detailed wetland hydrologic studies that have been performed typically involve an assessment of specific existing wetland hydrologic parameters (e.g., water balance terms), rather than a projection of hydrologic conditions associated with a proposed wetland replacement project. Therefore, few, if any, completed studies are available from which to develop standard procedures.

In the wetland replacement projects completed to date, the level of hydrologic planning and design has varied considerably, depending on the type of wetland being replaced. Project staff have based many projects on their estimates of water elevation and fluctuation at the replacement site under preproject conditions. They have assumed that these parameters, often on the basis of rough estimates, one-time measurements, or both, would remain constant after project completion. Understandably, this approach has resulted in many wetland replacement projects being only partially successful or even failing eventually.

From the design perspective, project staff must keep in mind the following two important hydrologic considerations when siting and designing a wetland replacement project:

- Geomorphologic and hydrologic characteristics that are correlated with or exert control over the desired specific wetland hydroperiod must be understood so that project staff can use an appropriate strategy for siting and designing the replacement wetland. In this document, the research team recommends the use of the classification categories summarized in Appendix Table E-8 and discussed in Appendix Section E.3 as a conceptual approach for hydrologic design.
- Project staff must establish what hydroperiods are needed at the replacement site so that during the siting and design of the replacement area they can specify the desired wetland hydrology and hydraulic capacity, controls, and elevations to support the vegetation planned for the site. In the *Guidelines*, the wetland hydroperiod classification scheme (Table 5) for freshwater wetlands is based on a summary of the U.S. Army COE classification system (Environmental Laboratory,

TABLE 5 U.S. Army COE wetland classification system

Zone	Name	Duration	Comments
I	Permanently inundated	100%	Inundation > 6.6 ft mean water depth
II	Semipermanently to nearly permanently inundated or saturated	> 75% - < 100%	Inundation defined as ≤ 6.6 ft mean water depth
III	Regularly inundated or saturated	> 25% - 75%	
IV	Seasonally inundated or saturated	> 12.5% - 25%	
V	Irregularly inundated or saturated	≥ 5% - 12.5%	Many areas having these hydrologic characteristics are not wetlands
VI	Intermittently or never inundated or saturated	< 5%	Areas with these hydrologic characteristics are not wetlands

1987); for tidal fresh water and saltwater, it is based on the three tidal zones: high marsh, intertidal, and subtidal (Appendix G).

Project staff typically will encounter the following five major hydrology conditions in wetland replacement projects. (The geomorphologic and hydrologic categories and characteristics that correlate with or control specific wetland conditions are discussed below and in detail in Appendix Sections E.3.2.4 and E.3.2.5.) The five hydrologic conditions are as follows:

- Tidal (both salt and fresh),
- Riverine—rivers and streams (perennial and intermittent),
- Lakes and ponds,
- Wetlands supported by rain and surface water runoff, and
- Wetlands supported by groundwater (including springs).

This grouping is highly simplified for purposes of the *Guidelines*. Therefore, project staff should exercise caution in assessing hydrologic conditions, because multiple factors may influence the conditions at a given site. For example, the complex circumstances at some replacement types—such as those associated with groundwater and surface water runoff inflows—may be an important consideration in the wetland replacement design, as described below and elsewhere in the *Guidelines*.

Project personnel must recognize why some replacement sites that may fall into the tidal, lake and pond, or riverine category may not require detailed site-specific hydrologic studies. For those wetland replacement types, it may not be necessary or even desirable for project staff to complete extensive hydrology studies to establish site feasibility, if they can accurately assess the reliability of the site hydrology using biological benchmarks, acquire accurate secondary information (e.g., stream gauging records, long-term well records, and long-term tidal elevation data), or both—all of which may confirm reliable water conditions, such as sufficient water elevations at the site.

If insufficient hydrologic conditions exist—such as water levels or elevations that fluctuate dramatically, are too far below grade, or do not match the desired wetland replacement type—the task of site selection probably will be much more difficult, because the wetland hydroperiod is affected and sometimes even created by the project itself. Thus, project personnel may require more detailed hydrologic and possibly hydraulic studies during site selection to ensure that they can establish adequate hydrology at the site to maintain the desired wetland type or types. They must show in the development of the project design that adequate hydraulic capacity and controls exist or can be provided at the site.

In Figure 2 (also Appendix Figure E-36), the research team recommends a conceptual framework that project sponsors may use as a guide to evaluate the adequacy of hydrology at a site and to complete the design for the replacement wetland. Throughout these evaluations, they must keep in mind the project's original goals and objectives, considering whether a given factor contributes to establishing the replacement site. Appendix Section E.3.4 presents in more detail the actual methods and approaches for evaluating the hydrology of a site. A brief explanation of the recommended steps follows:

- Step 1: Establish the hydrologic position of the replacement site within the watershed (i.e., there is a hydrogeologic and geomorphologic relationship between the proposed wetland site and the larger hydrologic unit of which it is a part). Select which category or categories may be applicable (Appendix Figure E-8).
- Step 2: Evaluate baseline (i.e., pre-project) water surface elevations (WSELs) and WSEL fluctuations at the replacement site (if applicable). The evaluation can either be on the basis of secondary information and use of biological benchmarks, or it may require the collection of site-specific information—such as long-term groundwater monitoring or surface water monitoring—to determine reliability, variability, and predictability of water elevations at the replacement site.
- Step 3: Evaluate the post-project hydroperiod or hydroperiods of the wetland as follows:
  - Tidal, lake and pond, and riverine wetlands: The primary task will involve determining if baseline WSELs and WSEL fluctuations can be maintained through proper hydraulic design, because baseline and post-project hydroperiods will be essentially identical.
  - Surface-water- and groundwater-supported wetlands: Probably, no baseline conditions exist because the site was not previously a water body. Also, the replacement wetland itself will have a significant effect on the hydroperiod. Therefore, hydrologic and hydraulic studies will be needed to assess the water balance—inflows and outflows—of basin wetlands, whether supported primarily by precipitation or surface runoff or primarily by groundwater.
- Step 4: Prepare topographic, hydraulic, and engineering design of the replacement wetland. Project staff may delay this step until later, unless it is necessary to advance the design to confirm the feasibility of the candidate site.

Thus, the project sponsor should focus first on assessing what supporting hydrologic conditions, such as tidal and riverine, exist within the study area. Sites having a reliable and predictable hydrology—tidal, lake and pond, or, to a lesser degree, riverine—will be more desirable, depending

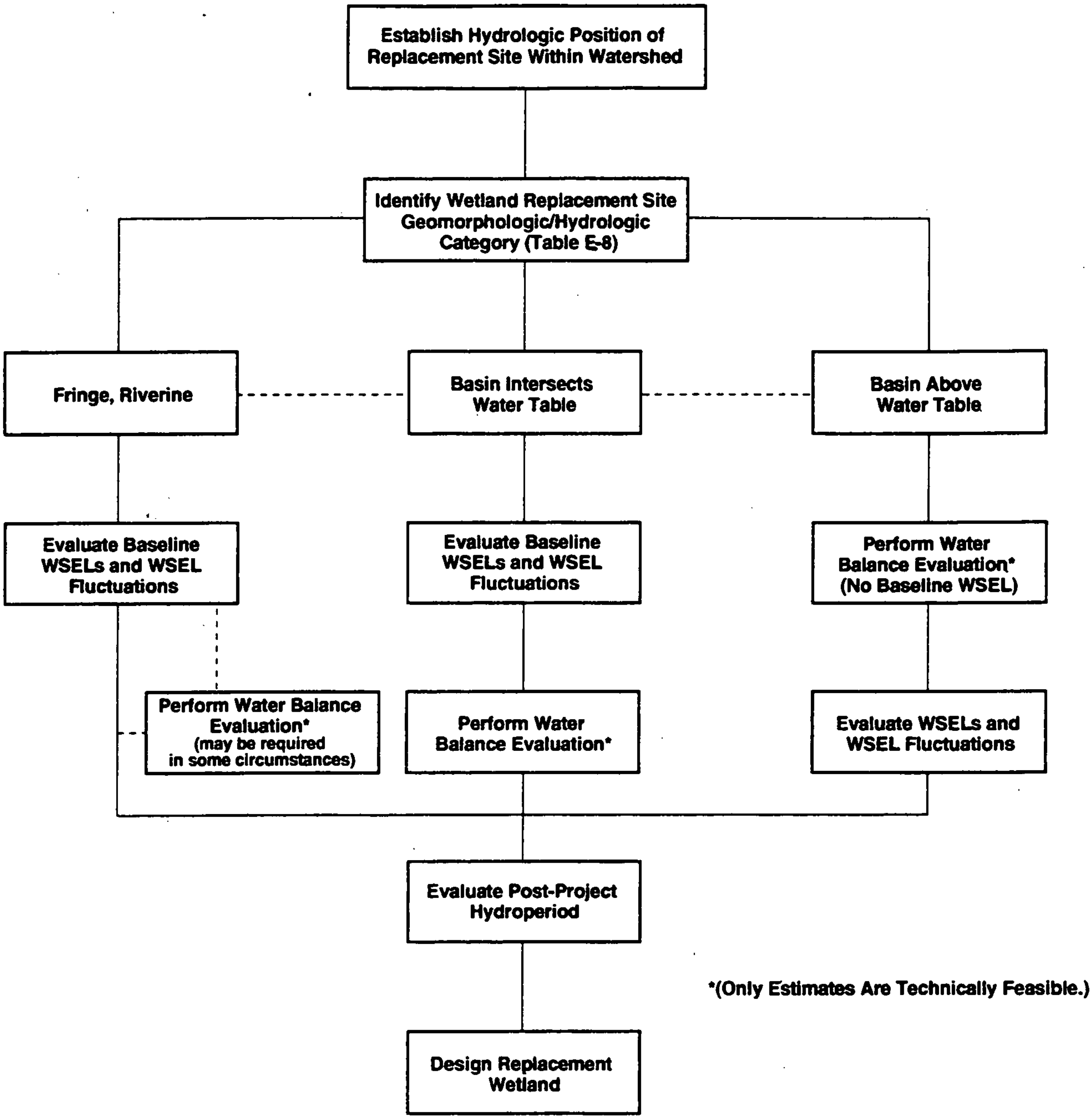

Figure 2. Framework for hydrologic design of replacement wetlands.

on goals and objectives, than those sites where the hydrology, and therefore the supporting water body, is highly variable and unpredictable. If the elevations of the supporting water body are unreliable for the wetland type desired, then project staff may need to consider several options, including the following:

- Evaluating what hydraulic controls and site modifications are needed to establish the desirable water elevations (hydroperiod) at the project site so that they can determine if they are adequate to support the desired plant communities,
- Evaluating the creation of an artificially perched hydrologic condition to support the desired wetland hydrology (e.g., by sealing the wetland bottom to reduce infiltration), and
- Selecting another site.

For those wetland replacement projects supported by surface water or groundwater, or those in the riverine category, the research team recommends that a combination of inflow sources be used if possible, because hydrologic conditions usually fluctuate seasonally and yearly. Using more than one water source may provide some additional assurances that the wetland replacement will not fail during droughts. However, most replacement wetlands supported by tidal flows or large lakes and ponds have, for all practical purposes, predictable and reliable hydrologic conditions that usually eliminate the need to consider the use of combined hydrologic sources. In addition, some riverine systems can have relatively stable hydrologic conditions, making it unnecessary to consider multiple inflow sources.

When hydrologic and hydraulic modeling is necessary to predict complicated surface water or groundwater systems, stream meander stability, water exchange rates, site stability during peak inflow rates, or combinations thereof, project staff should evaluate water conditions through field monitoring.

Specific factors to consider when siting and designing a replacement wetland under one of the five aforementioned hydrologic conditions are as follows:

- Tidal: Project staff should consider several elements for potential replacement sites driven by tidal water. They include
  - Tidal amplitudes,
  - Shoreline substrate characteristics, and
  - Fetch.

  Project staff can estimate tidal amplitudes by using the National Oceanic and Atmospheric Administration's (NOAA's) regional tide and tidal current tables. Project staff also can use these data to estimate tidal ranges and the elevations at which the site should be established. Although valuable in the decision-making process, tidal data must be augmented with biological benchmark information obtained from nearby areas before project staff can develop final plans and specifications. A NOAA tide gauge station may be miles from the replacement site and, therefore, may not accurately reflect the tidal range of the site in question. For some areas, NOAA tidal data may not be available or may be generated only from mathematical modeling on inland tidal bays. On such bays, tidal amplitude is only a matter of inches, and the major tidal influence is wind. Under these circumstances, project staff should not rely on NOAA tidal data, even as an approximation of tidal amplitude. Instead, project staff must use biological benchmark data.

  Project personnel also must consider shoreline substrate characteristics next to or on the proposed replacement site. Very coarse sand or gravel on a shoreline often indicates high wave energy. That wave energy, coupled with the potential abrasiveness of wave-borne sand, gravel, or both on installed plant material, could cause the replacement project to fail. Additionally, project staff must also consider the fetch at the site (i.e., the exposure of the shoreline to open water and, thus, to potentially high wave energy). Generally, project staff should avoid sites with a fetch of more than 1 mi unless protective measures, such as breakwaters, are part of the design. Sites with less than 1 mi of fetch, however, may have conditions causing sufficient wave energy to jeopardize the replacement project.

  Although high energy shorelines generally do not make good candidates for replacement wetlands, successful projects are possible. They require that the replacement wetland be constructed inland from the shoreline and connected to the shoreline or water by culverts. Such sites usually require shoreline stabilization to prevent erosion and to protect the dike from high-energy waves that could destroy the site.

  Shore configuration is another factor that project personnel should consider. The importance of shape can be shown by the example of a replacement wetland in a sheltered cove versus one on a peninsula that receives wave energy on three sides. Erosive waves generated from boat traffic and offshore deep water may be other limiting factors for tidal areas.

- Rivers and Streams: Diversion of water above the average base flow on rivers and streams—both perennial and intermittent—may be a fairly reliable source of water for a site. Deep, steep-sloped channels, steep topography, or both will not automatically exclude a site as a candidate, but earth-moving costs could make the project too expensive.

  Local stream gauge data or flood studies, if available, are valuable support data for the decision-making process. Generally, USGS stream gauge stations are listed on the USGS maps. Stream gauge data are usually available through the regional USGS office or a state flood-plain management agency. Without these data, project sponsors may have to obtain site-specific stream information to verify that the hydrology will support the desired area (Chapter 4). However, if recent on-site or adjacent stream gauge data are available for the replacement site, then additional time-consuming and costly gauge studies may not be necessary.

  Project staff should also review state and local water rights issues and permit requirements, particularly in the West and Southwest, for the proposed project. The purchasing of water rights or the delays caused by the per-

Under no circumstances should models be used to replace actual field groundwater or stream monitoring.

mitting process can increase project costs substantially. Additionally, a stream's classification (e.g., trout production stream) may preclude from use any candidate site associated with the stream.

- Lakes and Ponds: Lake and pond shorelines frequently are conducive to wetland replacement projects. Issues for project personnel to consider during the site selection phase include seasonal water fluctuations, water quality, and—on large bodies of water—wave energy, shoreline sediment composition, and fetch (Section 2.5.1).

  The zonation patterns of wetland vegetation (biological benchmarks) on or next to the site are good indicators of its water regime. Biological benchmarks, however, may be absent from smaller bodies of water or recently created ponds. Under some circumstances, biological benchmark data can be collected on nearby bodies of water that have the same water regime as the replacement site. Alternately, the plant communities could be given design elevations on the basis of their known depth preferences, using supporting data from a nearby body of water. In this situation, project staff will have to determine elevational differences in relation to the water level. When conditions are uncertain, water level studies may be needed before the project staff can finish the final design.

  On smaller bodies of water, drawdown because of evaporation may be a problem. Water level changes are also a concern in bodies of water managed for waterfowl or shorebirds, used for irrigation, or scheduled for maintenance drawdowns, such as lakes and ponds.

- Wetlands Supported by Precipitation and Surface Runoff: When these basin wetlands occur above the permanent water table, they must be supported entirely by precipitation and the resulting surface water runoff. Therefore, their hydroperiods are extremely sensitive to the following:
  - The natural variation in precipitation—the most important independent variable that must be considered—which can only be predicted statistically;
  - Surrounding land use, which affects the runoff coefficient, and, therefore, the amount of runoff (inflows) that can occur;
  - Soil type and infiltration rates within the wetland site (outflows); and
  - Evapotranspiration, the loss of water through plants, and evaporation from water bodies. (Under most circumstances the evapotranspiration rate—outflow—will represent a very small fraction of a site's water loss.)

  Unlike riverine or tidal wetlands, the design of groundwater- or surface-water-supported wetlands may require that project staff perform a water balance analysis in which inflows from precipitation and surface water runoff are balanced against outflows from evapotranspiration, infiltration, and surface water discharge. The resulting change in water storage over time determines the wetland hydroperiod. Appendix Section E.3.3.5 contains examples of water balance analyses for basin wetlands. Appendix Section E.3.3.6 elaborates on the water supply dependability of basin wetlands, which is based on the natural variability of rainfall and, therefore, can be predicted statistically.

  In many cases, these wetlands can be expected to go dry seasonally, during extended low-precipitation periods, or both. Such conditions do not represent wetland failure—they are a natural consequence of precipitation variability; therefore, the possibility of "dry-out" conditions must be predicted and allowed for in the wetland replacement design. If dry-outs are likely to occur, then the choice of plant material for the project must be species that will tolerate such conditions. No standardized methodology for the statistical design of these wetlands exists, nor have the necessary statistical parameters for such a design been developed yet from available National Weather Service precipitation data. Appendix Section E.3.3.6 discusses key elements and considerations associated with predicting conditions under precipitation of varying periods.

- Wetlands Supported by Groundwater: Groundwater-supported wetlands may intercept and be supported by a permanent groundwater table. Accurate prediction or measurement of groundwater inflows to and outflows from a wetland are very difficult—if not impossible—and the hydraulic relationship between surface water in a wetland and adjacent groundwater may vary greatly over the area of the wetland and over time. Therefore, the research team believes that it is usually not practical to perform water balance analyses for proposed basin wetland restoration projects that will intercept the water table. The team recommends that the hydroperiod of such wetlands be estimated by monitoring groundwater levels at the restoration site and by projecting the variation of these levels over time, using either analytical-numerical groundwater models or extrapolations

The presence of hydric soil conditions at a given depth does not indicate sufficient groundwater to supply a replacement wetland.

Groundwater-fed wetlands are the least understood of any wetland type and the most difficult to construct successfully.

from long-term records supplied by nearby monitoring stations (e.g., USGS monitoring wells). Appendix E discusses the nature of shallow groundwater fluctuations.

Because fluctuations can be substantial, and considering that long-term groundwater monitoring data for areas near a proposed restoration site usually will not be available, the research team concludes that wetlands supported primarily by groundwater are the least understood and the most difficult to construct successfully. If project staff are considering groundwater as the water source for a replacement wetland, they must document that the water elevations are relatively stable over time.

The presence of water, or the presence of soils affected by water, at a given depth does not imply sufficient groundwater at that depth to support a wetland. Furthermore, the presence of a natural groundwater-driven wetland does not ensure that there will be enough additional groundwater present to support the enlargement of the existing wetland to create the replacement area.

2.5.4 Soils

> **VEGETATION AND SOIL TYPE**
>
> **Wetland vegetation can be established on most soils and subsoils. Under most circumstances, only pure clay, rock, and pyritic subsoils prohibit plant growth.**

Wetland vegetation can be established on almost any type of soil (Appendix F). Depending on the project goals and objectives, specific soil types (e.g., organic soils) may be required on the basis of conditions found at the existing wetland to be replaced. Readers are cautioned, however, that some very important design and construction considerations may override the goal of selecting a site with one or more soil types or establishing one soil type over another in design. Appendix F describes many of these considerations, particularly with regard to use of organic soils. During site selection, however, the research team believes the project sponsors should focus on the overall suitability of the site soils and then consider, if necessary, specific soil augmentation requirements in the design phase to meet project goals and objectives.

Substrates of solid clay and solid rock are not conducive to plant growth. Additionally, some subsurface soils are pyritic (i.e., when exposed to oxygen they become highly acidic and will inhibit plant growth). The local SCS office will have information on soil types associated with pyritic subsoils in the area. Project personnel may obtain general information on lithography and stratigraphy by reviewing geology and geomorphology maps, usually available through the regional USGS office.

Staff also may obtain valuable information on soil type through field investigations using a bucket auger, provided that the final design elevation is not too far below existing grade. If final design elevations are incomplete because hydrologic studies are needed, project staff should take borings within the vertical range in which they expect final elevation to fall.

Project personnel will use the subsurface soil data to determine whether an appropriate substrate is present at the design elevations—both for plant growth and for the proposed hydrologic regime. In addition, soil data will verify that the mitigation design is workable. For example, if the design requires a perched water table, it is essential that project staff learn if the soils are impermeable enough to hold water. If the design requires groundwater to feed the wetland, then the soils must be permeable enough to permit groundwater discharge into the site. Project staff must use the subsurface soil type to calculate approximate infiltration rates for the area.

The U.S. EPA has established procedures for determining percolation, or infiltration, rates in the soil (U.S. EPA, 1980). Although these techniques were devised to determine the permeability of an area and, therefore, its feasibility for constructing septic systems, project personnel can modify the procedures easily to establish if a site will be impermeable enough to retain water. Appendix F presents this specific method in detail.

Depending on the design of the wetland replacement, other factors associated with the soils may be important. Are the soils stable enough for the designed slopes? If dam or dike structures are part of the design, then the suitability of the soil type for each use must be analyzed. If the soils are not stable enough for the designed slopes or stable enough to support dams or dikes, the project staff may have to bring in appropriate fill to build these design features.

The substrate conditions may be unsuitable because of old dumps or landfills, construction rubble, contaminated soils (e.g., hazardous waste and substances), or combinations thereof on the site. County or municipal governments may have maps that designate the locations of known dumps or contaminated sites. Historic photography may also be useful in identifying them. Even if there are no records, be aware of the following signs in the field, which may signify the presence of a previously unknown dump site or abandoned hazardous waste:

- Uneven topography with sparse or young stands of vegetation: These conditions may indicate that the site is an old landfill. Auger samples should quickly provide supporting evidence in the form of bits and pieces of municipal garbage. The presence of cinder ash or construction debris in the sample is also a good indicator that the site was used as a landfill.
- Chemical odors associated with the soil sample and oily sheens on damp soil or on the surface of groundwater: These may indicate chemical spills or chemical dumping on the property.

In general, project staff should avoid garbage landfills and contaminated sites as replacement wetland areas, although this is not necessarily the case for sites containing construction debris, cinder ash, or both. If soil borings and chemical testing reveal the material is not contaminated and that the elevations of the final grade are within appropriate soil types, then these may be feasible sites. Additional project costs may be incurred, however, for chemical testing of the substrate and for the removal and disposal of the materials when construction begins.

2.5.5 Water Quality

Water quality issues, particularly water clarity and nutrient loads, are an important consideration if wetland replacement involves establishing submerged aquatic vegetation (SAV). Most SAV have specific light requirements that limit or prevent their establishment in turbid water (Appendixes E and J).

Because poor water quality can hinder the success of a wetland replacement project, project staff should evaluate the water quality of both surface water and groundwater inputs for the replacement site and identify specific pollutants and sources within the drainage areas. Seasonal fluctuations in water quality parameters—such as nutrient loads, dissolved oxygen levels, and turbidity—can be expected, especially in urbanized or intensively farmed agricultural areas. These fluctuations may influence certain components in the plans and specifications for the replacement site.

Project staff can evaluate potential water quality problems by using existing data from local monitoring studies conducted near the replacement wetland site or by collecting such data on their own. Local health departments or community groups may have water quality information on the area in question, especially if it is being used for recreational purposes. If recent data are not available, it may be wise for project staff to initiate a new study because some factors—changes in land use or upgrades of treatment facilities—may make data obsolete.

When on-site mitigation requires the replacement wetland to be constructed next to an existing or proposed highway, the replacement area may receive stormwater runoff that contains pollutants from highway operation and maintenance-related activities. Pollutant concentrations and loads may range from very low to high. Depending on the replacement wetland goals and objectives (e.g., performing functions such as sediment and toxicant retention or wildlife enhancement), runoff may be a benefit or detriment to the wetland replacement site. Regardless, stormwater runoff may need to be diverted from the site because of federal, state, or local regulations and policies.

Specific constituents that may need to be evaluated include the following:

- Sediments: Sediment loads could have a detrimental effect on the replacement site. Increased turbidity caused by suspended sediment in water reduces light penetration and affects aquatic life. In particular, heavy sediment loadings can adversely affect planted vegetation in the initial years of the site by burying plants and altering substrates and grades. In addition, many pollutants, such as nutrients and heavy metals, may be attached to sediments, making the sediments a source of contamination as well.
- Nutrients: High concentrations of phosphorus and nitrogen may result in algal blooms and the eutrophication of water bodies. Nutrient loads can degrade habitat and water quality with surface algal scum, odors, water discoloration, decreased oxygen levels, and toxin release (Schueler, 1992).
- Heavy metals: These come from various sources in a watershed, including surface-mined lands, point-source discharges, non-point sources (e.g., stormwater runoff), and natural sources. In some areas of the country, background metal loadings may be of significant concern. There is considerable controversy about using replacement wetlands as retention areas for heavy metals. Depending on the situation, however, the wetland may be an "acceptable sink." Coordination with regulators and natural resource agencies can help project staff to determine the acceptability of this practice in specific regions of the United States.
- Oil and grease: Petroleum hydrocarbons are known to be toxic to aquatic organisms, even in low concentrations; however, in low levels and under the right conditions, they may not affect the replacement wetland.
- Deicing salts: Sodium chloride (NaCl), the principal deicing agent used on highways in the northern states, can cause problems mostly because of chloride—high levels can stress freshwater plants. In particular, many seedlings, shoots, and plugs may be especially sensitive to deicing salts. Underground plant structures, such as rhizomes and tubers, are also salt sensitive.
- Other constituents: Many other constituents may be of concern, but the need to monitor or investigate them is site-specific.

Numerous procedures have been developed for evaluating water quality. The Federal Highway Administration (FHWA) and SHAs have sponsored many research projects to characterize stormwater runoff from highways (Kobriger, 1984; Gupta, 1981; Harris and Lindstrom, 1985; Moxness, 1986; and Mar et al., 1982). Also, methods have been identified for evaluating pollutant loadings (Driscoll et al., 1988; Kramme et al., 1985; Mar et al., 1982; and Racin et al., 1982) and for minimizing impacts of highway stormwater runoff (Versar and Camp Dresser and McKee, 1988). When a proposed wetland replacement site is next to a proposed or existing highway, the project staff must consider the potential impacts of highway runoff in developing the plans and specifications.

One method of predicting soil loss and, indirectly, potential sediment loads, is a semi-empirical equation developed by the Agricultural Research Service (Gray and Leiser, 1982). Known as the Universal Soil Loss Equation (USLE), the method uses erosion field data under natural and simulated rainfall. The USLE may have limited application when detailed topography is unavailable for the site; it is not suitable for large-scale comparative evaluations. According to Gray and Leiser, (1982), however, "In spite of its limitations, the USLE provides a simple, straightforward method of estimating soil losses and of evaluating the effectiveness of soil loss reduction measures." Many other methods exist, although the USLE is fairly straightforward and is useful for screening candidate sites' vulnerability to sediment loads from adjacent upland sources. If high loads are predicted, it may be necessary for project staff to incorporate a presettling basin into the design or some other best management practices to reduce sediment loads to the area. If conditions are found to be severe, project staff may have to identify another site.

2.5.6 Wetland Replacement Acreage Requirements

> **ACREAGE FOR REPLACEMENT PROJECTS**
>
> **The actual acreage requirements for a replacement wetland project often exceed the acreage specified in the permit conditions.**

In many cases, the total acreage required for a successful wetland replacement project will be greater than the actual number of acres specified in the permit conditions. The following factors affect these requirements:

- Acreage Required: The total acreage required for a replacement project depends on the design objectives, the site's physical features, and the regulatory requirements for upland buffers around the replacement wetland.
- Physical Features: Wetland replacement projects frequently are next to existing wetlands, water bodies, or both. The acreage of the natural wetland, water body, or both usually cannot be credited in the total replacement acreage, although it may have to be included in the property acquisition.

  For example, topography not conducive to constructing a replacement wetland, including such features as rock outcrops, may be present. Although these topographic features can be used in the design of the wetland replacement, they usually are not considered part of its acreage.

  If wetlands are present, a wetland delineation of the replacement site will be needed to
  - Determine if sufficient upland acreage is available for construction,
  - Assess if there are wetlands present that require enhancement,
  - Verify and fix the location (on-site base mapping) of existing wetlands that cannot be disturbed or altered, and
  - Establish specific design requirements and construction specifications to protect existing wetlands during construction.
- Replacement Site Topography: Accurate site topography is essential to estimate earthwork (excavation) costs. Topographic surveys with 2-ft contours are generally sufficient, but 1-ft contours are preferred for more reliable cost estimates. Details about the precise location of all existing features, such as buildings, channels, tree lines, and culverts, are necessary. Without them, the project staff cannot design the grading plan and hydrology accurately.
- Design Features: Many design features require acreage beyond that needed for the replacement wetland itself. Depending on the site topography and the depth to the final design elevation, side slopes may require a significant amount of acreage. Although side slopes can provide valuable habitat and may be included in the buffer, they would not necessarily be considered part of the replacement acreage. Some designs include resting or nesting islands. If designed as uplands, the acreage for these may or may not be considered part of the replacement.

  In designs that require water control structures and dams or dikes, the berm needed to impound water would not be considered part of the wetland replacement acreage, even though it is an integral part of the replacement design.
- Buffers: Many states require upland buffers around wetlands; this requirement usually applies to wetland replacements as well. Buffer widths vary with jurisdiction, but they are generally between 25 and 100 ft. On large projects, the acreage required for the buffer could

be substantial. Other considerations could include buffers for endangered or threatened species habitat and even property-line setbacks that have been established in local zoning regulations.

- Drainage Area: It may be necessary to acquire the entire drainage area of the replacement wetland, particularly when surface water runoff is designed to drive the replacement wetland.

2.5.7 Landscape Context of the Site

The general goal of a wetland replacement project is to replace the wetland acreage and the functions lost because of some impact, such as a highway construction project. Project staff must verify that the proposed site can meet this goal. Although the initial site surveys may show that an area has existing natural features that will support the replacement wetland, such as adequate hydrology, factors external to the site may preclude it from consideration, as explained in the following:

- Surrounding Land Use: Surrounding land use can detrimentally affect a replacement wetland. Ideally, the site should be in a relatively undeveloped watershed and protected from future development through strict zoning, use of special land-use control measures (e.g., environmental easements, deed restrictions, and land trusts), or by outright purchase and management by a public or private conservation group. Without these ideal conditions, the project staff should choose a site with the lowest potential for development.

  If the site is in a watershed that is experiencing or is going to experience heavy development pressure, the project staff must evaluate potential impacts to the replacement wetland. Changes in water quality and volume could occur under the following conditions:

  - If the wetland site is downstream from development, sedimentation during development and construction can alter wetland grades, substrates, and hydrology.
  - As impervious surfaces in the watershed increase from development, greater volumes of water and extended periods of high water could change the site's hydrology.
  - As development increases, the quality of runoff water will decrease. Degradation includes higher water temperatures, increased pollutant and nutrient loadings, and increased turbidity.

  These site conditions will likely degrade the wetland and result in either outright failure of the project or, at a minimum, in the establishment of a less desirable vegetative community.

  Project personnel should evaluate nearby landfills, hazardous waste sites, junkyards, feed lots, or other potentially contaminated areas for their likelihood of contaminating the wetland replacement site, especially if it is downstream or will receive runoff from them.

  Staff also must determine the locations of utility and other rights of way for planning and construction phases. Access for maintenance and repair of nearby underground utilities may cause a continuous disturbance. Existing utilities or their installation with porous, granular backfill can intercept incoming water or drain the wetland. Aboveground utilities, such as overhead power lines and railroad rights of way, may have routine herbicide treatments in their maintenance programs that could jeopardize the site. Even if the replacement project does not include these rights of way, adjacent herbicide drift or runoff could be significant.

  Other right-of-way considerations include airport flight paths and buffers. A wooded wetland should not be next to active landing strips where trees, when mature, could become visual or structural safety hazards. Such wetlands also attract wildlife, including birds. Replacement wetlands near airports could increase bird populations in the area, thus increasing the risk of bird strikes and possible aircraft accidents.

- Shading: If the candidate site is heavily shaded by vegetation, plant establishment may not be successful unless extensive clearing is done.

  In situations where structures such as bridges and buildings may shade the replacement site, a shade study may be necessary. If less than 6 hours of sunlight per day is available during the growing season, then the site may be precluded from use as a replacement area.

- Access: Access is another important consideration. This includes access for construction as well as for maintenance, such as periodic cleaning of sediment basins, repair of structural elements of the project, or control of invasive species. A site with difficult access can incur substantial maintenance costs.

  However, site accessibility may increase undesirable use of the area. In some cases, site security may be an important element of the wetland replacement design. Because replacement wetlands often include large cleared areas, mud, and water, serious human impacts may result from off-road vehicles and vandalism to plants and water-control structures. Overall, the acces-

Human impacts to a replacement wetland can be substantial.

sibility of the site for maintenance and monitoring activities has to be balanced against the potential for human impacts on the area.

- Invasive Vegetation and Problem Animals: During site selection, project staff also must consider the potential for harmful invasive plants and problem animal species in the region. If the proposed replacement area is near or next to wetlands dominated by aggressive plant species, such as common reed (*Phragmites australis*), purple loosestrife (*Lythrum salicaria*), or cattail (*Typha sp.*), these species may invade the replacement site.

  Large concentrations of pest wildlife can be a problem (Appendix I). Deer, geese, beaver, muskrat, nutria, and carp can devastate a replacement site by consuming the installed vegetation. Muskrat and nutria can damage earthen water control structures with burrowing, while beaver can block inflow and outflow structures. Muskrat and geese also can deconsolidate sediments and destroy peat structure during feeding. After such feeding, very few plant species can recolonize the disturbed site. Geese can foul the water, causing water quality problems, especially in small ponds. Bottom-feeders, such as carp, can roil sediments, which reduces water clarity. Domestic and wild animals (e.g., goats, swine, and horses) also can be destructive.

- Landscape Ecology Context of the Site: Project personnel also should evaluate the importance of existing vegetative communities or habitat that may be found next to impacted wetlands. If personnel determine that the communities are important, they should become criteria in site selection. Presumably, the presence of such communities at a site may give that area priority over other candidate locations.

  Another consideration is whether the wetland is part of a larger wetland complex or is isolated. A single prairie pothole, vernal pool, or Delmarva Bay (Appendix D) may appear isolated, but in the landscape each may be part of a wetland complex for waterfowl feeding, resting, and nesting; amphibian breeding; and, particularly with prairie potholes, for hydrologic connections through the groundwater. The replacement wetland should, when possible, be designed and constructed within this same landscape context.

  Under some circumstances, the replacement wetland may serve a better purpose if designed and constructed to perform functions other than those being lost at the disturbed site as in the following instances:
  - The wetland to be lost is dominated by an invasive plant species. The replacement wetland could feature a plant community more beneficial to wildlife.
  - If the wetland to be lost is a type common in the region, the replacement could be designed as a less common type, such as an emergent palustrine wetland that replaces a forested wetland, thus creating habitat diversity.
  - The replacement wetland could be designed to provide habitat for threatened or endangered species.
  - In urban settings, the replacement wetland could be designed to treat urban stormwater runoff to improve water quality.

  In all of these examples, project personnel must verify that the proposed replacement site can support the wetland type being considered and that it fits into the ecological landscape of the region.

- Other Considerations: The presence of archaeological or historical sites on or near the site can either block or slow the project until further investigations are completed. If project staff determine that cultural resources are significant, resolution of conflicts pursuant to Section 106 of the National Historic Preservation Act requirements may prove too costly or may prohibit the use of the site for construction of replacement wetlands. Other issues to consider include the current zoning of the site and how a new use of it would change current and projected tax revenues for local governments. Additionally, project staff may need to address other institutional constraints, such as drainage districts, water rights, presence of threatened or endangered species, and farmland preservation issues. The availability of the site is also a consideration, because a willing seller makes the process easier and is better for community relations than condemnation proceedings. Finally, the presence of hazardous waste or substances can render a site unsuitable, depending on the type and extent of contamination. Before selecting a site, an initial site assessment (Phase I environmental site assessment) and possibly a preliminary site investigation (Phase II environmental site assessment) usually is required to assess whether potentially hazardous waste or substances are present.

2.5.8 Construction Feasibility and Cost-Effectiveness

> **FEASIBILITY AND COST**
>
> **Determining construction feasibility and cost-effectiveness is crucial to site selection. Appendix H provides more information on potential costs.**

During site selection, project staff must consider the potential costs of project implementation. They should estimate the depth-to-final-design-grade and thus cubic yards of material to be excavated and removed. They also should ascertain the suitability of the excavated material for use at the impacted

TABLE 6 Ideal conditions for wetland replacement sites

When present on the selected site, these conditions can make design and construction of the wetland replacement less difficult.
Sufficient, easily verifiable hydrology
Protected watershed
Minimal grading necessary
Good access (for construction equipment)
Surrounding land use compatible with the replacement wetland with no indication that substantial land use changes will occur
Sufficient acreage available
Local biological benchmarks
Available existing site data
Acceptable land acquisition costs
Lack of cultural resources or other site constraints

wetland site. If the excavation is extensive or the material cannot be used for other construction activities, such as roadways, the proposed site may no longer be feasible, especially if excavation material must be disposed of off site.

Site access during construction must also be evaluated. Will temporary roads or bridges have to be built? Will a temporary or permanent right-of-way agreement be required? If the proposed site is in an isolated area, mobilization and supply transportation could be costly. Isolated sites may prolong projects because of the time needed to move work crews to and from temporary lodgings to the work site and to move equipment to repair facilities. Such factors can add substantially to the project's costs.

If construction at the site necessitates permits for additional wetlands or sensitive habitats, delays may result. If endangered or threatened species are found on or next to the site, construction windows may be limited to seasons when the species are not breeding and rearing young or when they are altogether absent from the area. If dredging is required, project staff should limit it to periods when fish are not spawning.

2.6 SITE SELECTION

Using these site selection criteria, project staff should evaluate as many suitable sites as possible. A preliminary cut of candidate sites on the basis of one or more of the criteria can help reduce the number of candidate areas. As site selection progresses, one or two probable sites may emerge. Table 6 summarizes those elements that most often make a wetland replacement cost-effective.

If none of the candidate sites is suitable, project personnel will have to identify additional sites for study. It may be reasonable to reconsider sites initially rejected because of cost considerations but offering overriding benefits. In some cases, however, the project sponsor may have to modify the original wetland replacement goals and objectives to find a suitable replacement site.

2.7 DOCUMENTING THE SITE SELECTION PROCESS

Most often the project staff will document the results of the site selection process in the Wetland Conceptual Mitigation Plan or other environmental documentation required by regulatory agencies. Often, project sponsors may wish to prepare, or have prepared by wetland consultants, a separate site evaluation report with recommendations. Depending on the circumstances, project staff may have to conduct more detailed studies, such as hydrologic investigations. In the end, the information generated by these reports, whether summarized or not for the regulatory agencies, is necessary if the project staff are to make a final determination about the feasibility of the preferred site and if they are to avoid costly mistakes later on in the WRP.

CHAPTER 3

PREPARING THE CONCEPTUAL WETLAND REPLACEMENT PLAN

3.1 GENERAL CONSIDERATIONS

The project staff develops the conceptual plan for the wetland replacement at a level of detail sufficient to confirm, for internal review and for regulatory agencies, that the wetland replacement project design meets the goals and objectives set out in Step 1 of the WRP (Chapter 1). The conceptual plan describes the replacement wetland through use of drawings and notes or text. The project sponsor develops the conceptual plan, which, once approved, becomes the basis for preparing the final construction plans and specifications.

PLAN PURPOSE

The conceptual plan provides a qualitative overview of the wetland replacement and verifies to the project sponsor and regulatory personnel that the goals and objectives established in Step 1 of the WRP have been realized.

The development of alternate conceptual plans that provide the established goals and objectives may help cut costs.

Project sponsors may develop the conceptual plan for one or more of the reasons given below, or they may eliminate this step in the WRP for their particular project. Some project sponsors may have little reason to develop a conceptual wetland replacement plan if the project's scope or relative complexity does not warrant one. Instead, they may start directly on construction plans, once they have collected all necessary information to complete them. Whichever the case, sponsors can apply the EPW (Appendix J) to both conceptual plans and construction plans to verify that they meet the goals and objectives set out in Step 1 of the WRP.

3.2 REASONS FOR DEVELOPING A CONCEPTUAL WETLAND REPLACEMENT PLAN

Project sponsors may have several reasons for developing a conceptual plan as well as possible alternative plans to it. Reasons for doing so include the following:

- The conceptual plan verifies that a wetland can be developed at the selected replacement site and documents that it meets the goals and objectives established in Step 1 of the WRP (Chapter 1). This verification that the wetland replacement meets the goals and objectives is actually completed in the Site Selection Step of the WRP (Chapter 2) through functional evaluations of sketches or text about the wetland replacement. The project sponsor should be sure that the results of this verification appear in the final plan.
- The conceptual plan confirms the feasibility, desirability, and estimated cost factors, before project sponsors commit to the wetland replacement design or collect additional information and data to develop final plans and specifications. Although project sponsors should consider costs broadly in the Site Selection Step (Chapter 2), they also should develop alternate conceptual plans—each of which should meet the prescribed goals and objectives—so that they can look more closely at costs and then identify the most economical alternative to pursue. Landscape architect and construction and maintenance personnel should then review the conceptual plan to identify any features that could lead to problems in the final design, construction, and maintenance of the replacement wetland.
- The conceptual plan allows regulatory agencies to review and comment on the project early in the WRP. Agency review may identify modifications necessary to make the plan acceptable. Review at this stage can save time and money and can lessen the likelihood that the project sponsor might have to consider alternatives later in the WRP.
- The project sponsor or regulatory agencies may choose to announce the conceptual plan in Public Notices. These notices request comments on the proposed action.

The entire plan must be supplied in an 8.5-by-11-in. format for such announcements.

- A conceptual wetland replacement plan serves to identify and validate the types of additional information required. The information needed to prepare the final construction plans and specifications may be substantial and may require a long lead time to collect; therefore, such information needs must be established during this step of the WRP. Such information can include data on final grades, pool levels, and water diversion (to site) level in the water bodies (Chapter 4). When this information is available, project staff should include it in the conceptual plan.

3.3 CONTENT OF THE CONCEPTUAL WETLAND REPLACEMENT PLAN

There is no specific format for the conceptual wetland replacement plan, but the research team recommends that it consist of text and plans. These can be presented in various ways, including the following:

- A separate narrative with schematics attached showing a plane view and typical cross section;
- As plan sheets with plans and notes or statements that refer to the plans directly on the sheets;
- As plan sheets with plans and sheets containing blocks of text; and
- As plan sheets with plans, notes, statements, separate text, or combinations thereof in the form of a report.

The plan sheets should be at a scale of 1 in. to 200 ft or more, depending on the size of the site and the amount of detail necessary. The plan sheet may be reduced for incorporation into the narrative report. Important sections may or may not be drawn to scale. In the experience of the research team, the text and plans may contain elements such as a summary and information on hydrology, general construction and grading, vegetation, and so forth. The researchers recommend that project sponsors contact the appropriate COE office or state agency to determine specific conceptual format requirements, because format requirements vary.

3.3.1 Summary Information

The conceptual plan should provide information about the replacement site, the goals and objectives of the replacement, project costs, and other related information as follows:

- A Summary of the Acreage and Type of Wetland That Will Be Lost and Replaced. This summary may be given in the text and should include information about any transition zone, buffer area, upland islands, and wetland areas to be enhanced.
- A Statement of the Goals and Objectives of the Wetland Replacement. This information also may be given in the text. It should include how the project sponsor determined the goals and objectives and how the proposed replacement design—as shown on the plan sheets—will achieve these goals and objectives. This statement should include a discussion of any functional evaluations of the wetland to be lost and the replacement wetland.
- A Discussion and Summary of Estimated Costs. Items to be placed in the text include construction, maintenance, and monitoring costs associated with the replacement wetland.
- Other Possible Considerations Relating to the Proposed Replacement Wetland. Other items for regulatory review include provisions for ownership and maintenance once the replacement wetland has been constructed and all permit stipulations have been satisfied (Chapter 7).
- The Proposed Monitoring Protocol and Schedule. This material can be described in the text (Chapter 8). It may also be required for regulatory review.

3.3.2 Hydrology

Because supporting hydrology is essential to a replacement wetland, the research team recommends that the conceptual plans document how project staff calculated that the hydrology would sustain the replacement wetland and at what probable water depths or tide ranges. This should include the following:

- A Discussion with Appropriate Calculations to Show That the Necessary Sustaining Hydrology Will Be Available. This information and supporting data should appear in the text. A preliminary water balance also should be included if biological benchmarks or reliable surface water elevations are not present. If the hydrology for the project has yet to be demonstrated, the narrative or plan sheets should detail what studies and monitoring the project sponsor will undertake to confirm that the final wetland meets the hydrologic goals and objectives of the replacement wetland (Chapter 4 and Appendix E).
- Water Depths (Seasonal, Temporary, or Permanent) or Tide Ranges. These data should be shown on the plans for the specified vegetative species and communities. Although additional hydrologic information may be necessary to produce final plans for nontidal wetlands, the conceptual plan should show probable water levels.

3.3.3 General Construction and Grading

Project sponsors should include information about the physical site in the conceptual plan, including data on grades, cross sections, construction approaches, and site constraints as follows:

- A Discussion of Information (Other than Hydrological) That Must Be Acquired. This information must be in hand before project staff can develop final plans and specifications (Chapter 4). Details about each category of required information should appear in the text.
- Existing and Final Grades. If known, this information should be included on the conceptual plan; if unknown at the time when the conceptual plan is prepared, a statement should be made that the information is unavailable but project staff are acquiring it. Details about other relevant physical features of the replacement wetland should also appear here (e.g., stream location and unusual substrates).
- Construction Approaches. In the conceptual plan the project staff should describe construction approaches to the extent that they are known.
- Typical and Clarifying Cross Sections. The conceptual plan should include an exhibit that shows typical and clarifying cross sections for the replacement wetland. If possible, a match line should be shown as a conceptual plan exhibit.
- Any Existing Site Constraints. The conceptual plan should identify construction and subsequent maintenance constraints at the replacement wetland, such as site-access problems.

3.3.4 Vegetation

The project sponsors also should provide information in the conceptual plan about the plant communities and the landscape plan for the replacement wetland as follows:

- Plant Communities and Their Acreages. The project staff who draw up the plans should include data on vegetation in the notes or text. They also should identify and describe the plant communities and their acreages and the location of open water, mud flats, channels, uplands, transition and buffer zones, and so forth.
- Landscape Plan. The project staff should provide a preliminary landscape plan for the replacement wetland, including the types of plant material to be provided.

3.4 TIMING THE SUBMITTAL OF THE CONCEPTUAL PLAN

Project sponsors should ascertain when their state requires that the conceptual plan be filed, because the requirements vary from state to state. In Ohio, for example, the conceptual plan must be filed with the Section 404 Permit application, and the plan must be approved as part of the Section 404 Permit approval. Once the conceptual plan is approved, project staff develop detailed plans before construction starts. Some states require that the conceptual plan be filed with the Environmental Impact Statement (Appendix B); other states do not require a conceptual plan—instead, the detailed construction plans are submitted with the Section 404 Permit application.

CHAPTER 4

OBTAINING ADDITIONAL INFORMATION FOR FINAL CONSTRUCTION PLANS AND SPECIFICATIONS

4.1 INTRODUCTION

The most important documents that project staff produce in the WRP are the plans and specifications. Experienced and knowledgeable wetland professionals must develop them. Furthermore, to ensure project success, the project designer must anticipate as early as possible in the WRP the timetable for acquiring all the information necessary for the final plans and specifications. The research team believes that most of the design information should be collected during site selection (Chapter 2). Project staff must acquire additional information for the final plans and specifications to determine final design specifications (e.g., the composition and density of plant communities, the shape and depth of the stream cut, and the type of exclusion fence). This information-gathering step should never involve collecting site-specific information needed to verify that the site is suitable for a wetland replacement project. Project staff should have completed site verification during site selection. The specific additional information requirements discussed in this chapter include details on the following:

- Reference wetlands,
- Soil seed bank studies,
- Hydrologic monitoring,
- Assessment of problem wildlife, and
- Assessment of potential vandalism problems.

4.2 REFERENCE WETLANDS

> **CAUTIONS**
>
> - Choose only commercially available plant species for the replacement wetland.

After the project sponsors have chosen the replacement site, a reference wetland (i.e., the site to be impacted or an alternative reference site) can be used during this step in the WRP to determine the desired plant composition and species densities for the replacement area. The reference wetland must have hydroperiods and vegetation similar to that specified in the goals and objectives of the replacement site so that plant data collected at the reference site can be matched with that of the hydroperiod and plant zonation at the planned replacement area.

To obtain this information about hydrology and vegetation, project members can sample the reference wetlands in many ways. They can identify plant dominance and density by using methods such as diameter-at-breast-height in forested areas or by determining density per square meter in random plots in herbaceous sites. Usually, project members can collect sufficient information for design purposes by estimating canopy cover, stem density, or both. The research team does not recommend controlled sampling methods, such as point-centered-quarter method and belt transect, because of the cost and time required to perform them.

4.3 SOIL SEED BANK STUDIES

The use of a donor seed bank for vegetative source material has been gaining in popularity as a possible low-cost technique for establishing vegetation at wetland replacement sites: In the *Guidelines*, the term "seed bank" refers to all materials—including seeds, spores, mycorrhizae, tubers, and other propagules—within excavated soils that could lead to establishing vegetation when spread over the replacement site.

If the project staff proposes that a donor seed bank from the impacted wetland be used at the replacement wetland, project staff may need to conduct a soil seed bank study, which may yield valuable information on the species composition of the seed bank, as well as the abundance and distribution of the

> **During site selection, project staff should collect most of the information needed to verify that a site will support a wetland replacement project and to confirm site feasibility.**

species (Welling et al., 1988). With this information, project staff can predict what vegetation may become established from the donor seed bank. The research team regards the practice of topsoiling—the use of soils from the impacted wetland at the replacement site—as highly experimental and recommends caution if project staff consider this practice as an option. Appendix Section F.4 provides more detailed information on the use of seed banks in wetland replacements, including potential problems with the practice.

4.4 HYDROLOGIC MONITORING

During the gathering of additional information, project staff should complete their verification that the hydrology present can support the replacement wetland (Chapter 2 and Appendix E). These additional hydrologic data are necessary to establish the final design criteria. There are two hydrologic regimes that may require additional monitoring at this point in order to verify their adequacy: river-and-stream-based and groundwater-based systems. These are discussed in the following sections.

4.4.1 River and Stream Monitoring

Project personnel may need to conduct river and stream monitoring to determine the position, design, and depth of the inlet structures to the replacement wetland. The two types of monitoring that may be required are as follows:

- Stream elevations and
- Stream velocity and flow monitoring (including measurement of stream cross sections).

Stream elevation gauging is often necessary if project staff are to determine where normal water levels are along a bank. In many states, only water above the average base flow can be diverted from a stream and used as a measure. Thus, project staff should use gauging data to decide what water levels are considered above this flow. They should then use these data to determine the depth and design of the stream bank cut needed to divert the water above the average base flow, as well as to determine the final grade of the replacement wetland. Stream elevation gauges may be needed at each point along the stream where water may be diverted to the replacement wetland. A hydrologist or hydraulic engineer familiar with stream flow monitoring and watershed investigations should be consulted when establishing a river and stream monitoring program.

Project staff should use stream velocity and elevation data to establish what volume of water is available for diversion into the replacement wetland (Appendix E). Project staff must know the volume available during typical storm events—for example, the amount of water that can be diverted during a summer thunderstorm during the seasonal drought period. Project staff must understand that the design must be appropriate for the volume of water available during seasonal droughts, and, therefore, they also must understand that calculating the average water available for the year is not useful: any water in the replacement wetland above the pool elevation will exit the system to the stream and will not be available during the seasonal drought. Stream velocity and elevation data ultimately will allow them to determine the appropriate stream bank cut and final design elevation for the replacement wetland.

4.4.2 Groundwater Monitoring

Groundwater monitoring is necessary in wetland replacement projects that rely on groundwater to drive the system or to augment other water sources. Wetlands supported by this hydrology type are more difficult to duplicate than those driven by other hydrologies (Appendix E). Monitoring establishes when groundwater elevations are at their lowest and at what depth and identifying water-level fluctuation problems. Generally, such monitoring consists of the project staff establishing a series of wells (piezometers) throughout the site. The research team highly recommends that continuous recording equipment be installed on some of the wells. Project personnel should monitor these wells biweekly to monthly. They should then use the data they collect to establish the direction and pattern of groundwater flow, as well as the lowest groundwater elevation for the site, so that they can determine the final grade for the replacement wetland. At least three wells are necessary to establish the direction of groundwater flow. Wells should be placed in a triangular pattern. At a minimum, the research team recommends monitoring these wells for a year. Even data collected over this time may not adequately characterize the groundwater fluctuations of the area, for reasons described in Appendix E; however, a shorter monitoring period may be acceptable if recommended by a geohydrologist or a wetland expert familiar with groundwater hydrology at this site.

Calculating average water volumes available for the year yields meaningless information. The crucial information that project staff must determine is this: what water volumes are available during seasonal droughts that occur during the growing season?

4.5 ASSESSMENT OF PROBLEM WILDLIFE

Many animals, both wild and domestic, can be destructive to a wetland replacement project. They can include deer, rabbit, geese, carp, swine, horses, cattle, and goats (Appendix I). Although comprehensive surveys of these animals are generally not warranted in the WRP, assessing population densities will help the project staff determine what exclosure techniques may be needed. The best way to determine what wild animals could present a problem is for project personnel to contact the area wildlife agency office for census data for these species. In addition, crop and landscaping damage reports and automobile-animal collision data may be available from these agencies for larger animals. If population levels of certain species indicate that they could seriously affect the replacement wetland, project staff may need to take appropriate design measures to avoid or minimize this potential problem.

4.6 ASSESSMENT OF POTENTIAL VANDALISM PROBLEMS

Many wetland replacement projects in the early stages of development are flat bottomed, slope-sided, and sparsely vegetated, and they contain areas of shallow water and mud. Unfortunately, this early successional stage often attracts off-road vehicle use. If the replacement site is in a densely populated area, project staff should include access restrictions in the design plans. Deep water channels, fencing, and other types of barriers can help prevent vandalism, including the wanton destruction of plant materials and engineered structures, such as check dams, weirs, and outlets (Appendix I).

CHAPTER 5
PREPARING CONSTRUCTION PLANS AND SPECIFICATIONS

5.1 ACCURACY AND CLARITY

The construction plans and specifications for wetland replacement are the most important documents produced in the WRP. They are the permanent record of the project, and they (or the as-built plans) will serve as a baseline for follow-up evaluations during postconstruction monitoring. They must be sufficiently detailed so that they can be used for

- Verifying that they will achieve mitigation goals and objectives using a functional assessment procedure;
- Bidding and construction;
- Scientific, engineering, ecological, and biological review and so forth; and
- Verifying the as-built condition during the postconstruction monitoring period.

The plans and specifications must be correct, complete, and accurate if the established goals and objectives are to be achieved. The research team cannot overemphasize the importance of the construction plans and specifications. As stressed throughout the *Guidelines*, the plans and specifications must demonstrate to reviewers that

- The hydrology of the replacement wetland is clearly understood and known to be reliable, so that the assignment of vegetation communities to the proper elevations can be made with confidence; and
- They are site-specific, sufficiently detailed, and reliable so that when constructed according to them, the replacement wetland will achieve the goals and objectives established in Step 1.

Drawings, specifications, and plan notes must be clear and concise so that they can be understood by the contractor. Of particular importance are the

- Elevations of grades and water control structures (e.g., inlet and outlet controls) so that the required wetland hydrology can be established; and
- Specifications, plan notes, and landscaping and planting plans, which must be accurate and correct (i.e., the species or vegetation communities must be designated for their proper elevations).

To ensure that the plans and specifications are clear, understandable, and contain all the necessary information, project team members—including wetland replacement specialists—should review them before bid-letting. The research team recommends that the plans and specifications be subjected to a functional assessment to ensure that they will achieve the goals and objectives established in Step 1 of the WRP (Chapter 1). The team also recommends that a formal quality assurance and quality control (QA/QC) program be implemented to verify the accuracy of all calculations, quantities shown, and the location of structures and other design features and construction requirements. A QA/QC program is important for preventing or minimizing costly mistakes during construction. The QA/QC evaluation of the completed plans should be fully documented and incorporated into the project record. Any design modifications resulting from the review should be fully documented in the project record.

If the plans and specifications contain any engineered items, such as water control, diversion, conveyance, and detention features, or other items that require engineering, usually a licensed engineer or landscape architect (allowed in some states under certain circumstances) must seal and stamp the documents that contain them. Finally, the research team recommends that construction and maintenance personnel review the plans and specification to ensure that the construction and maintenance details are feasible.

5.2 FORMAT

Because all project sponsors will have their own formats for bid packages, the plans and specifications will have to comply with them. Generally, however, the research team recommends that the technical considerations for construction plans and specifications appear in five sections as follows:

- Summary information,
- Hydrology,
- General construction and grading,
- Vegetation, and
- Sediment stabilization and erosion control.

Project staff should be sure that plans and specifications present these sections clearly. Information requirements for each section are summarized in Table 7 and detailed below. If a project sponsor's plan format differs from the suggested items, the research team recommends that these five sections be incorporated into the plan.

5.2.1 Summary Information

If project personnel previously developed a conceptual wetland replacement plan (Chapter 3) and included summary

The single most severe flaw with many current wetland replacement plans and specifications is that the designed hydrology and/or the relationship between this hydrology and the associated vegetation are not clear.

information, it may be redundant for them to provide summary information on the construction plans and specifications. However, this summary information is important for the project sponsor's and for regulatory agencies' consideration, as well as for purposes of establishing a public record and for tracking the wetland replacement's history. The research team recommends that summary information include

- Wetland Types and Acreage Involved. This can include a summary of, or a statement explaining, the acreage and the type of wetland to be lost and what will be replaced; what wetland areas are proposed for restoration enhancement, or both; what buffer, transition, and upland habitat areas are involved; which areas are being given replacement, or mitigation, credit, and combinations thereof.
- Results of Functional Evaluations. If not provided with the conceptual replacement plan (Chapter 3), the project staff should include the results of any functional evaluations they performed (Chapter 1) of the wetland to be lost and of the replacement site.
- Goals and Objectives. The summary information should include the goals and objectives of the wetland

TABLE 7 Technical considerations for construction plans and specifications

Section & Summary Information to Include (Not all information listed necessarily applies to all projects):	
Summary Information	
Wetland types and acreage involved Results of functional evaluations Goals & objectives Costs	Earthwork calculations & topsoiling requirements Provisions for ownership Maintenance Monitoring protocol & schedule
Hydrology	
Hydrology summary (illustrated on plans & described in writing)	Assumptions or modeling data Hydrologic verification
General Construction & Grading	
Notes Plans Materials Construction timetable Benchmark locations Access points Important site features Construction limits Areas to be graded & backfilled Typical & atypical conditions sections	Stream/channel dimension & configuration Details for construction of all structures Slope stabilization techniques Special considerations Specifications for deconsolidation of substrate Maintenance procedures Material disposal requirements Clean-up procedures
Vegetation	
Lists of species for planting/seeding Lists of acceptable substitutes Local sources of plant materials Field collection instructions Native plant restrictions Special conditioning instructions Planting timetable Areas to be vegetated, identified by method Details for slope stabilization with vegetation Identification of party responsible for marking planting zones	Criteria for acceptable plant material Plant handling instructions Planting & fertilizing instructions Special planting techniques Wetland topsoiling instructions Seeding instructions Soil amendment details Watering/irrigation requirements Wildlife control structures Guarantee requirements Vegetation maintenance requirements
Sediment Stabilization & Erosion Control	
Plans for the entire area must be prepared according to local requirements	

replacement and, if they arose from the functional evaluation of the wetland to be lost, then project staff should state how these goals and objectives have been realized through the functional evaluation of the replacement wetland.

- Costs. These include estimated preconstruction costs (e.g., site selection, right-of-way acquisition, pre-design investigations, and engineering and design) and construction and postconstruction costs (e.g., maintenance, monitoring, and reporting) for the wetland replacement (Appendix H).
- Earth Work Calculations and Topsoiling Requirements. The summary should specify the volumes of cut, fill, and topsoiling and whether conventional soils, wetland soils, or both are required.
- Provisions for Ownership. The summary should indicate who will own the site once construction is complete.
- Monitoring Protocol and Schedule. The summary should state how success will be determined; it also should describe the reporting methods for the project (Chapter 8).
- Maintenance. It should state what routine maintenance will be done—such as weeding, culvert cleanout, and watering and irrigation. It should also specify over what period of time these activities will be done and, where applicable, the source and quality of water to be used.

5.2.2 Hydrology

If the hydrologic studies and analyses produce voluminous data and results, it would be helpful if project personnel developed a Hydrology Report that they would make part of the construction plans and specifications. In any case, they would still provide in the Notes any summary statements regarding the designed hydrology.

Where they apply, the following elements should be included at least in summary in the Notes and in detail in the Hydrology Report:

- Hydrology Summary. The project staff must summarize the conclusions from all hydrologic evaluations in the Notes of the plans so that any person reviewing the documents will clearly understand the hydrology to be associated with the replacement site. Examples of such summaries appear in the "Examples of Hydrology Summaries." The examples illustrate that it is important to show on the plans and to provide in writing in the Notes a description of all the water levels expected to prevail at the wetland replacement site. Project staff should show clearly the invert elevations of all water control structures, both intake and discharge. Omitting these statements is the most severe flaw that project staff can make in wetland replacement plans. Project staff also must be sure that the documents clearly show and state in the Notes what the designed hydrology is and what the specified plant species are in relation to that hydrology.
- Assumptions or Modeling Data. Project personnel must state clearly all of the assumptions they made in the analysis, including inferences about how these assumptions will affect the resulting hydrology and hydroperiods. If the assumptions relate to the transfer of data from one watershed to another where the replacement wetland is, then project staff should present the data or information that—at least in part—validates the assumptions made. Similarly, if they use hydrological modeling, then they should present the information—in the form of field data collected at the wetland replacement site—that validates the model and assumptions.
- Hydrologic Verification. Any time that project staff propose to connect a wetland replacement site to an existing wetland, they should conduct a hydrologic analysis to verify that the hydrology can sustain the existing and the replacement wetland. They should perform this analysis during site selection (Chapter 2) and, possibly, during information gathering (Chapter 4). Then, they should summarize the analysis and conclusions in the appropriate hydrology section on the plans and, if provided, in the Hydrology Report.

5.2.3 General Construction and Grading

The general construction and grading plans and specifications must be sufficiently complete and specific that the general contractor has to make no decisions that could affect the success of the project. Examples of specifications that leave too many decisions to the contractor appear in Table 8.

WATER LEVEL AND GROUNDWATER CONCERNS

The plans and notes must clearly describe all of the applicable water levels (pool, high, low, MHW, MHHW, MLW, MLLW) that will prevail at the wetland replacement site. Invert elevations of all water control structures, both intake and discharge, must appear clearly on the plans as well.

Because of uncertainties associated with groundwater-driven replacement wetlands, project staff should base construction on hydrologic and geohydrologic study results. These wetlands should be vegetated only after the hydrology stabilizes and any discharge structures that control the wetland's pool level have been adjusted, where necessary (see Example F on pg 53).

TABLE 8 Common mistakes encountered on wetland replacement plans and specifications

Unsuitable Specification (taken from actual plans and specifications)	**Criticism**
"Exact locations of plants shall be determined in the field by the planting contractor based on hydrologic tolerances."	The exact locations of plants should be shown on the plans. Most planting contractors are not familiar with the hydrologic tolerances of plants.
"All plant material shall conform to the current issue of the *American Standard for Nursery Stock* published by the American Association of Nurserymen."	This is not applicable for most wetland plant material. The acceptable condition of the plant material must be specified.
"Watering of plant material shall take place at the end of each day for fourteen (14) consecutive days after planting has been completed. The watering shall completely saturate the soil and partially immerse the plant material."	This is excessive, even if planted during a hot and droughty time. What if it rained? Generally, thorough watering should be completed at the time of planting and every 2 weeks thereafter during the first growing season, should the soils dry.
"Install plant material as soon as possible."	If it is important to plant as soon as possible after the delivery of plant materials to the job site, then give a time frame; e.g., "plants shall be planted within __ hours following delivery."
"All plants shall be hardy under climatic conditions in the locality of the project. All plants shall be typical of their species or variety and shall have a normal habit of growth. They shall be sound, healthy, vigorous, well branched, and densely foliated when in leaf. They shall be free of disease, insect pests, eggs or larvae. Root systems shall be healthy and well developed."	Typical boilerplate. State: "Plants shall originate from hardiness zone ___." Define a "normal habit" and refer to a sketch in the plans. What is sound, healthy, vigorous, etc. to one person, may not be to another. Specifications must be written so that the decision regarding "acceptable" will be the same for any inspector, e.g., "roots shall be white and developed through the sides and bottoms of the peat pots."
"All plant material shall be obtained from local sources within a 150 mile radius of the project site."	The 150-mile radius is arbitrary and not validated. What does this ensure? The Research Team recommends that project staff <u>not</u> specify the use of native plants unless they believe them to be essential to project success. In this event, they should provide specifications for the collection of seed or plants at precise location(s) where collection is permitted (Appendix G.2).

TABLE 8 Common mistakes encountered on wetland replacement plans and specifications (*continued*)

Unsuitable Specification (taken from actual plans and specifications)	**Criticism**
"Plants shall be grown in saturated conditions for a period of at least one year or long enough for the root system to have developed surface feeding roots similar to plants found in saturated conditions."	An inspector's nightmare. An inspector should not be expected to know what surface feeding roots look like. If such conditioning is necessary, specify only the time for which the plants should be conditioned (e.g., 6 months, 1 year, etc.).
"Plant material shall be planted in existing soil with each planting pit excavated to size sufficient to contain the entire root-stock or the entire root-mass without cramping."	How is cramping determined? Specify instead: "The planting hole shall be ___ inches larger than the root mass"
"Plants shall be guaranteed by the contractor for a period of three years."	Specifications regarding guarantees should indicate under what conditions the contractor would not be held responsible for the guarantee (e.g., loss of plants due to herbivory, vandalism, salt build-up in the sediments, ice pulling plants out of ground, or improper assignment of plant with regard to designed hydrology).
"Stone gradually blends into wetland basin."	How is "gradually" determined? Specify the required slope.
"Crushed stone shall be placed over filter cloth and compacted to minimize infiltration and erosion."	Erosion of what? Compacted to what degree? "Minimize" to what extent? Crushed stone over filter fabric will control erosion of the underlying sediments. Specify: "Crushed stone shall be compacted until the infiltration of water is ___ inches per hour or less."
"The information shown on these plans is for the convenience of those concerned only. The correctness or completeness of the information is not warranted or guaranteed. The contractor shall verify all information to his own satisfaction."	Information on the plans must be complete and correct. Verification should <u>not</u> be left to the contractor.
"Proposed contours and elevations are approximate. The contractor shall field verify all finished elevations before planting."	Proposed contours and elevations on the plans must be exact.
"Specific field elevations for the basin bottom may be adjusted slightly during construction to allow for unanticipated field conditions."	There should be no "unanticipated field conditions" that would change elevations as critical as these.

TABLE 8 Common mistakes encountered on wetland replacement plans and specifications (*continued*)

Other Frequent Errors	Criticism
Specifying plant species and plant conditions (i.e., container, bare root, etc.) that are not available commercially	Designers should research plant availability so that only obtainable plant species and conditions are specified.
Failure to specify acceptable substitutes for the primary plant species	This decision should not be left up to a contractor or a plant supplier. Acceptable substitutes should always be specified.
Incorrect assignments of wetland plant species to hydroperiods, depths of water, and/or positions within the tidal ranges due to a lack of understanding about the wetland plant tolerances and/or a failure to utilize biological benchmarks	See Appendix G for information on plant tolerances. See Chapter 1 for use of biological benchmarks.
Specifying seeds that are not commercially available and weights of seeds that are clearly arbitrary and failure to provide proper techniques and time of year for seeding	Only specify seeding when the technology for successful seeding is known and when the seeds are commercially available or arrangements can be made for their collection.
Specifying topsoiling when this is not necessary	Topsoiling is generally unnecessary and, if specified, inflates the cost of the project (Appendix F).
Specifying the planting of bare root trees and shrubs under hydric conditions	Even though bare root plants are inexpensive, their fibrous roots are often stripped upon processing, and new roots develop poorly in anoxic sediments. Consequently, low survival can be expected when planting bare root plants in hydric conditions.

The research team recommends that the general construction and grading sections of the plans and specifications include, but not necessarily be limited to, the following items:

- The project elevation data, with all water elevations tied to it;
- Acceptable tolerances in the final grades;
- A restatement of any element in the construction timetable that is critical for project success;
- A restatement of any element in the special considerations and conditions for construction that is critical for project success; and
- A restatement of any item in the special conditions of the wetland permit that relates to construction.

The following items may also be necessary:

- Plans. All plans should be scaled at 1 in. to 100 ft or larger (i.e., 1 in. to 50 ft) and show 1-ft contours or less throughout the final grades of all wetland areas that are particularly sensitive to slight changes in elevation. Spot elevations at all critical locations should be given (e.g., the inverts of existing and constructed streams, the tops of banks of existing and constructed streams, the inverts of all water control—including stream diversion—structures, and the bottom elevations of deep water areas).
- Materials. Project staff should place in the specifications any details, requirements, quantities, and precise descriptions for all listed materials (e.g., stone, added topsoil, wetland topsoil, and geotextile materials). Summary tables could be included on the plans.
- Construction Timetable. Project personnel should clearly place the construction timetable on the plans. Poor construction timing is often linked to problems with or failures of wetland replacement projects. Project staff must develop a thoughtful construction timetable that does not lead to inflated construction costs yet ensures that as few problems as possible will arise from construction delays. Examples G and H, below, illustrate two different construction timetable issues that may be critical to project success.
- Benchmark Locations. Project staff also should show the location of all physical benchmarks on the plans, with their corresponding elevations clearly identified.
- Important Site Features. Features, such as access points and property lines, should appear on the plans.
- Construction Limits. The construction or work limits at the wetland replacement site should appear on the plans. Project staff also should identify the acceptable construction staging areas and limits of disturbance to prevent the contractor from disturbing sensitive resources—such as wetlands or other important habitats—at the construction site.
- Areas to Be Graded and Backfilled. Areas to be graded below the final grade and then backfilled with conventional topsoil or wetland soils to the final grade must appear clearly on the plans and sections. Project staff also should discuss them in the specifications. When a certain soil type is required for the vegetation, they should state clearly what it is. Backfilling with acceptable soils may be necessary after sealing a site with a clay liner or when existing soils are unsuited for the specified vegetation (Appendix F).
- Typical and Atypical Condition Sections. In the plans the project staff must show sections for all typical and atypical conditions (e.g., a cross section for a typical segment of the replacement wetland or a cross section illustrating a single connection to a stream).
- Stream and Channel Dimensions and Configurations. If stream and channel dimensions and configurations have been modeled to ensure configuration stability from erosion or deposition, project personnel should state this in the plans and specifications, so that the stream or channel can be constructed according to plan.
- Details for Construction of All Structures. Project staff must provide details in the specifications and in the sections of the plans for the construction of all water control, conveyance, and diversion structures and other structures, such as stone revetments, stone armoring, stone aprons, bulkheading, and concrete head walls. As indicated in Section 5.1, a licensed engineer may have to seal the plans and sections of plans that contain the design of these structures.
- Slope Stabilization Techniques. Plans should show stabilization augmentation approaches for any slopes that may be unstable in the presence of vegetation. Stabilization techniques may include use of stone armoring, combining appropriate geotextile materials with seeding and planting, or combining appropriate geotextile materials with stone armoring. Slope stabilization requirements in the presence of vegetation will vary with site conditions (e.g., soil types and conditions, fetches over open shallow water, fetches over open deep water, water flow rates in constructed streams and ditches, and currents generated by winds and tides). The research team generally regards slopes steeper than 5 to 1 (horizontal to vertical) at the water-land interface as too steep to be stable without structural augmentation. Similarly, the team considers slopes steeper than 3 to 1 above and below the water-land interface as too steep to be stable without structural augmentation.

SUBSTRATE WORK

The substrate associated with all areas to be vegetated needs to be deconsolidated (decompacted) following construction to depths of 0.5' in areas where herbaceous vegetation is to be planted or seeded, and to depths of 1.0' in areas where trees and shrubs are to be planted.

EXAMPLES OF HYDROLOGY SUMMARIES THAT WOULD BE PLACED IN NOTES

The following examples summarize the designed site hydrologies that might be included in the Notes on the plans. These statements should be useful to a reviewer in understanding wetland replacement site hydrologies and then assessing the appropriateness of the specified plant species and communities and the respective elevations to which they have been assigned. Actual summaries may deviate from these examples, because they reflect the results of site-specific hydrology evaluations and conditions. To assess whether or not the site hydrology is accurate and correct and the site has been engineered correctly, the reviewer will probably need to review the site's Hydrology Report.

EXAMPLE A: The pool level shown on the plans is expected to persist 12 months of the year, even during severe rainfall shortage and drought conditions. In this case, the large watershed provides sufficient surface water following a 0.25 in. precipitation to bring the replacement wetland from a dry condition to a pool-level condition. Also, analysis shows that geologic occlusions provide for springs that discharge groundwater throughout the year to the replacement site. No biological benchmarks are available for the replacement wetland. For details, please refer to the Hydrology Report (part of the construction plans and specifications).

EXAMPLE B: Surface water runoff and direct precipitation are the sole sources of water for the wetland replacement site. The Keyport silt loam (KeA) soil provides for a perched water table with initially moderately slow infiltration rates that are expected to reduce with time because of organic input to the soil, resulting in sealing. Clay lining of the wetland replacement area to further minimize water infiltration is considered unnecessary.

Calculations and assumptions detailed in the Hydrology Report predict that the pool level will vary from that shown on the plans to 0.5 ft below during the months of November through April. During normal years of precipitation, the wetland replacement site is not expected to go dry (i.e., 1.5 ft below the shown pool level) for longer than 1 week during the growing season of May through October. During drought years, however, the site may go dry for periods of up to 2 months during the growing season.

Please refer to the Hydrology Report to review all assumptions and calculations. No biological benchmarks are available for the replacement wetland. To ensure successful vegetation establishment, watering to maintain moist soils throughout all elevations from the shown pool level and below will be necessary during the first growing season (see specifications for vegetation).

EXAMPLE C: The five flood-plain biological benchmarks used to establish the wetland replacement grades are shown on the plans. These benchmarks establish that the wetland grades range from elevations 261.5 ft to 269.0 ft. Vegetation indicators of biological benchmark species are FACW throughout elevations 261.5 ft to 265.5 ft and range from FACW to FAC throughout elevations 266 ft to 269 ft.

Groundwater throughout the existing wetlands ranged between 1.5 ft to 2.1 ft below the surface grades on 18 October 1990 and between 0.6 ft to 1.2 ft below surface grades on 4 February 1991. Groundwater throughout the wetland replacement site on these dates ranged from 0.0 to 0.4 ft above those in the existing wetland areas.

Stream water is diverted (see plans and sections) through an 88 ft long, 20 ft wide (with 4 to 1 side slopes), and 2-ft-deep riprapped swale to the wetland replacement site at an elevation of 260.5 ft, which is 2.3 ft above the "high" base flow for the stream, as determined during the period of 16 February through 6 March 1991. This swale will convey a peak flow of 195 cubic ft per second from an elevation of 260.5 ft to an elevation of 260 ft. The volume of the wetland replacement site is 40,000 cu ft at an elevation of 260 ft.

- Special Considerations. Project staff should place in the specifications and state in the Notes all special considerations and conditions for construction that are critical to project success. For example, water may be required to minimize dust. Special provisions also may be required to construct irrigation and watering systems. In some cases, they may require electrical work for water pumps, although such items should be used only when absolutely necessary. (Situations where such considerations must be explained are discussed in Examples I through L.)
- Specifications for Deconsolidation of Substrate. The substrate associated with all areas to be vegetated should be deconsolidated after construction. Project staff should state the specifications for deconsolidation (i.e., through discing, ripping, plowing, or rototilling).
- Material Disposal Requirements. Construction debris disposal requirements should be identified clearly. Some

EXAMPLES OF HYDROLOGY SUMMARIES THAT WOULD BE PLACED IN NOTES (continued)

EXAMPLE D: The high-tide (water) level shown on the plans reflects the average of 12 biological benchmarks (standard deviation from the mean is 0.12 ft) that are within 1.1 mi of the wetland replacement site (see biological benchmark locations on the inset of sheet 2 of 12 of the plans).

The low-tide (water) level shown on the plans reflects the tide range of 4.6 ft at the closest NOAA tide station, which is 6.8 mi down river from the wetland replacement site. Observations of the low-tide (water) elevations at the wetland replacement site during days that the NOAA tide tables predict normal values indicate that the low tide (water) level shown on the plans is approximately correct.

The highest yearly spring-tide (water) level is shown on the plans to be 1.6 ft above the high-tide level. This elevation is estimated from the NOAA tide tables daily predictions. The low marsh, high marsh, and scrub-shrub wetland zones shown on the plans are derived from the 12 biological benchmarks. The high and low limits of these zones have standard deviations from the mean of 0.15 and 0.07 ft, 0.04 and 0.11 ft, and 0.11 and 0.02 ft, respectively.

On the basis of information about existing vegetation throughout the site and on three measurements taken in August 1990, the water salinity at the site is not expected to exceed 0.5 ppt. The top of the 36-in. diameter corrugated metal pipe (CMP) connecting the river to the wetland replacement site is set at 1.0 ft below the estimated low-tide level at the site (see plans and sections). This will prevent floating debris from entering the site, while allowing fish to come and go. The volume of the site at the normal high water level is 1,463,616 cu ft. The 36 in. CMP will allow an estimated 1,955,000 cu ft to flow in or out of the site within a 6-hour period, allowing a head of 0.1 ft (2 percent slope). Consequently, the CMP will not restrict tidal flow to to and from the site.

EXAMPLE E: Water will be diverted (an estimated 65 percent) from Long Creek to the wetland replacement site when creek water levels are 0.4 ft above the high base flow value. Details of the maintenance-free water diversion structure and the 115-ft-long and 32-ft-wide concrete conveyance channel are given on sheet 5 of 14 of the plans and specifications.

Fourteen months of stream gauge monitoring indicate that this 0.4 ft above high-base flow and higher water levels in the creek are achieved following a 0.2 in. or greater precipitation within a 1-hour period (see the Hydrology Report that accompanies the plans and specifications). Calculations given in the Hydrology Report indicate that 0.45 in. of rain within a 1-hour period is needed to fill the dry wetland replacement site to the pool level shown on the plans.

Because the 26-acre wetland replacement site is designed to be graded to 5 ft to 11 ft below the lowest groundwater levels determined during the 14 months of piezometer monitoring (see Hydrology Report), a constant flow of groundwater is expected to be discharged through the sandy soils into the wetland replacement site.

states leave this responsibility to the contractor; however, because of the nature of wetland replacements, specific requirements should be included so that unwanted material is not left at the site and that waste materials are disposed of properly.

- Cleanup Procedures. In addition to the preceding items, general site cleanup requirements should be identified. Cleanup items include removal of trash, brush, equipment, and stakes.
- Maintenance Procedures. If maintenance is to be part of the general construction and landscape contract, project staff should place in the Notes all of the details about how this maintenance will relate to the general maintenance of the site. Similarly, they should describe in the vegetative section how the maintenance relates to the site's vegetation. If maintenance is to be performed under a separate contract, project staff should not include it as part of the plans and specifications (Chapter 7).

5.2.4 Vegetation

Vegetation data—such as landscaping tables, lists, notes, and specifications—and the relationship of vegetation to the site hydrology are an important part of the construction plans and specifications. Vegetation specifications must be site specific, accurate, workable, sensible, dependable, and meaningful. The research team cautions that project staff

EXAMPLES OF HYDROLOGY SUMMARIES THAT WOULD BE PLACED IN NOTES (continued)

Even without this groundwater contribution, more than sufficient water from Long Creek is expected to be supplied during normal precipitation years to maintain the pool level shown on the plans. During dry years when the precipitation is up to 50 percent below normal, the pool level is expected to be maintained through groundwater contributions (see water budget calculations given in the Hydrology Report).

When water at the site is at pool level, water diverted from Long Creek flows through the wetland replacement site and is discharged back into Long Creek 1.2 miles down stream.

EXAMPLE F: The wetland replacement's water source is groundwater and direct precipitation. There is no surface water contribution to the hydrology. The designed pool level for the wetland replacement is 114.0 ft, which is the invert of the 48 in. CMP discharge pipe. The bottom elevation of the wetland replacement is 111.0 ft, which is 3.1 in. to 3.5 ft below the lowest groundwater levels found from piezometer monitoring during the period of 3/1/89 - 11/31/89 (see Hydrology Report).

The hydraulic conductivity and specific yield of the fine sand soils are 0.28 ft/day and 0.21, respectively. Discharge of groundwater into the site is estimated to be 17,000 cu ft and 448 cu ft, using the Ibrahim and Brutsaert and the Dupuit equations, respectively (see Hydrology Report). Following excavation, groundwater discharge into the site is expected to take anywhere from 14 days to 1 year to achieve the designed pool level.

Because of the qualitative nature of the groundwater calculations and the variance between the predictions from the two equations used, installation of the wetland plant materials should not take place until the pool level has been reached and the site's hydrology has stabilized. The landscape contractor should be prepared to install the wetland plant materials as early as the year of construction and up to 2 years thereafter (see Vegetation Section of the Plans and Specifications).

should not stipulate conditions and materials that have not worked in other projects or that are otherwise suspect. Wetland replacement projects are not experiments. The team recommends that project sponsors try new approaches and test new ideas but not at the expense of overall project success. In general, the team recommends that the project sponsor test unproven approaches and ideas only in small areas (i.e., 5 percent of the total project area) to avoid jeopardizing the entire project.

Use of boilerplate landscape architecture specifications that are incorrect, improper, or do not apply to wetland replacement projects is a common problem in vegetation specifications for replacement projects. Other mistakes frequently encountered on wetland replacement plans and specifications are listed in Table 8. Specific vegetation items that project staff should address in the plans and specifications are as follows (Refer to Appendix G for extensive information regarding vegetation):

- Lists of Species for Planting and Seeding. Lists should provide
  - Botanical and common names of plant species;
  - Types of plant materials (e.g., dormant bare root, growing bare root, unrooted cutting, balled and burlapped, container, fiber pot, plug [seedling], plug [collected], and seed)
  - Heights of trees and shrubs only (not of herbaceous material);
  - On-center spacings of plant materials and whether the spacings are within areas or within clusters;
  - Quantities of plant materials;
  - Fertilizer formulations, rates, and quantities;
  - Soil amendments required, such as compost and sand; and
  - Seeds and seeding rates.
- Lists of Acceptable Substitutes. Because of the commercial shortages of many species and types of plant materials, project staff should include lists and tables identifying acceptable substitutes.
- Local Sources of Plant Materials. The names, addresses, and phone and facsimile numbers of all acceptable local sources of plant materials should appear in the vegetation section.

PLAN REQUIREMENTS

Clearly show the relationship between vegetation and the designed hydrology on the plan views and in the sections.

EXAMPLES OF CONSTRUCTION TIMETABLE ISSUES

EXAMPLE G: In a replacement project where most vegetation work is specified for completion by seeding the wetland species, this task has to be completed within a narrow window (Appendix Sections G-3 and G-7). Otherwise, seeding may have to be postponed for 1 year. The postponement might violate a permit condition, leave the site vulnerable to erosion and invasion by nuisance plant species, or both.

EXAMPLE H: Earthwork completion should be coordinated with the installation of certain species of plants to minimize the impact of salt buildup in the soils. Staff should time plant installation to minimize the effect of wildlife and livestock grazing or of drought. They should specify the precise windows for planting to ensure the maximum possible success of vegetation establishment.

- Field Collection Instructions. Generally, field collection is recommended only if the donor site is agency-permitted for destruction. Otherwise, every effort should be made to specify commercially available plant materials. If field collection of materials is permitted, project staff should
  - Identify the permitting agency or agencies,
  - Detail which species may be collected,
  - Recommend the method or methods of collection,
  - Identify the optimum time for collection,
  - Establish the maintenance requirements for the plant materials following the collection, and
  - Identify the precise locations of acceptable donor sites that meet the approval of any applicable agency or agencies.
- Native Plant Restrictions. Requiring the inclusion of native plant restrictions in plans is controversial. There is some concern that using nursery stock (i.e., genetically homogeneous nursery stock or stock from another region) may be detrimental to the persistence of the site and overall project success. Another controversy concerns specifying the use of local native plants. A native plant species is defined as one originating or occurring naturally in a particular region (e.g., the northeastern or southwestern states). A local native plant species is defined as indigenous, endemic, or nearest population to species with wide geographical ranges that will almost always develop locally adapted populations called ecotypes. Ecotypes result from the genetic responses of populations to habitats and are distinguished by morphological or physiological characteristics or both. Most wide-ranging species are composed of a continuum of ecotypes, each differing slightly in morphology or physiology. The research team recommends that native plant species should always be specified for use in wetland replacement projects. On the other hand, for reasons detailed in Appendix Section G.2, the research team thinks that local native plants should be specified only if

EXAMPLES OF SPECIAL CONSIDERATIONS & CONDITIONS FOR CONSTRUCTION

EXAMPLE I: If the wetland replacement site is to be graded substantially below groundwater elevations, then detailed and very specific dewatering and grading instructions and sequences must be provided and adhered to.

EXAMPLE J: To obtain the proper grades within the given tolerances in tidal areas, it may be important to exclude the tide from the replacement site during grading or to conduct the grading when the tide is out. Similarly, it may be important in nontidal areas to grade while water is excluded from or pumped out of the site.

EXAMPLE K: Sheet piling may be required to provide temporary earthen support or, where temporary water diversion structures will be necessary, to allow for proper construction.

EXAMPLE L: Special construction techniques and/or equipment (e.g., low ground pressure equipment and construction mats) may be required to minimize effects on existing wetlands or to complete the site grading properly.

Project sponsors should avoid specifying anything for a project that has not been successfully accomplished by others.

Project staff should specify to plant "in the dry" whenever feasible, because it is difficult and time consuming to plant and fertilize properly under water. In addition, plants "in the wet" may float out, jeopardizing the success of the project.

they are known to be critical in achieving success and the project goals and objectives. In addition, the research team recommends that the questions or items in Appendix Section G.2 on the feasibility of using native plants should be addressed before local native plant species are used.

- Special Conditioning Requirements. The specifications should detail any special conditioning and timing requirements for preadapting plants to site conditions (e.g., acclimating them to water salinity or hydric soils). These requirements should be reasonable. Although many wetland replacement projects have specified the need to acclimate plant materials to hydric soils for up to 1 year, no one has yet demonstrated scientifically that this is necessary.
- Planting Timetable. project staff should include recommended times for planting the materials. If planting can be done during different seasons of the year, the plans should identify the acceptable types of plant materials by season (i.e., winter, spring, summer, and fall). Wetland replacement sites generally can be planted—but not seeded—during any season of the year. In certain instances, however, the site's hydrology may not be expected to stabilize or to achieve the designed pool level rapidly. In such cases, planting may have to be delayed for up to 1 year or more following the construction of the replacement site. project staff must clearly identify such instances in the plans and specifications so that the landscape contractors bidding the job understand any uncertainties associated with obtaining the necessary plant materials and with scheduling the work.
- Areas to Be Vegetated, Identified by Method. The project staff should clearly label, on the plans, all of the planting and seeding zones for each species. They also should label open zones that have been designated for natural colonization, areas requiring topsoiling with wetland soils, and experimental work zones. Associated elevations for all of these areas should be clear on the plans.
- Details for Slope Stabilization with Vegetation. If slope stabilization is to be achieved with vegetation, project staff should include details for seeding or planting in these areas and, where applicable, explain how geotextile materials will be combined with vegetation.
- Identification of Party Responsible for Marking Planting Zones. Project personnel should indicate who is responsible for staking or flagging the zones before planting or seeding (e.g., the project engineer, landscape architect, the landscape contractor, or the general contractor).
- Criteria for Acceptable Plant Material. Criteria for ensuring the quality of plant materials at the time of delivery or pickup at the nursery should appear in the planting specifications, along with precise descriptions of what is considered acceptable and not acceptable for the specified plant materials.
- Plant Handling Instructions. Plant specifications should include instructions for the handling, storage, and maintenance of plant materials delivered to the job site.
- Planting and Fertilizing Instructions. Specifications should describe planting and fertilizing, details about the size of the planting hole, the underground depth of planting, disposition of excess soils after planting, placement of fertilizer, and so forth.
- Special Planting Techniques. If planting "in the dry," project staff must include directions for the removal of water from the site before planting and for the return of water after planting. If planting "in the wet" (i.e., under water), they should give directions and describe techniques for properly installing plant material and fertilizer so that these items do not float out of the planting holes.
- Wetland Topsoiling Instructions. If wetland soils are used for topsoiling, or "mucking", project staff should provide specifications for obtaining, storing and stockpiling, maintaining, and spreading the soils. The research team believes that topsoiling with wetland soils should be considered experimental and, therefore, either be relegated to a small section of the replacement site or that the topsoiled areas be landscaped as non-topsoiled sites. Even though topsoiling with wetland soils shows great promise for certain replacement types, there are not yet any reliable technical specifications for doing so. When they become available, they are likely to vary according to the geographic region and the vegetative composition of the wetland whose soils are to be used (Appendix F).
- Seeding Instructions. If seeding is to be performed, project staff should indicate
  - Appropriate techniques for application or broadcasting;
  - The need to use a "filler," such as sand, to dilute the seed to ensure uniform ground coverage;
  - Whether it is necessary to seed in the dry or in the wet;
  - When to seed; and
  - When and how to fertilize, if required.

  Too often, project staff specify seeding when seed is not commercially available or when the technology for

Wildlife depredation is considered one of the most serious problems for successful wetland establishment (Appendix I).

seeding the species has not been developed. As a cautionary note, project sponsors should beware of specifying commercially available "wetland seed mixes." They often contain undesirable invasive species that have little wildlife value.

- Soil Amendment Details. If soil amendments are to be used, project staff should provide details about the proportions to use, how to mix them, and what equipment, if any, might be required (for more information refer to Appendix F).
- Watering and Irrigation Requirements. Project staff must indicate clearly what watering requirements are necessary to maintain moist soils throughout the root zones—or to remove salts because of evaporation from the root zones—during the plant establishment period (i.e., the first growing season). Watering to maintain moist soils often will be necessary for wetlands that are seasonally or temporarily flooded, particularly in regions of the country that typically experience droughts during the growing season. Where droughts occur, it may be impractical to provide the necessary water through a contract with a landscape contractor and may be more economical to design and specify an automatic irrigation system for the replacement site. Although it is beyond the scope of the *Guidelines* to cover irrigation thoroughly, the research team suggests that project staff place details for irrigation systems in the plans and specifications or in the terms of a separate contract for the service.
- Wildlife Control Structures. If project staff expect wildlife grazing to be a problem, their specifications should include the construction of and timing for installing wildlife enclosures, other management controls, or both. If they propose the trapping and relocation of wildlife, they should state how it should be done and what permits are necessary. These statements about long-term wildlife management should appear in the specifications for maintenance, because it probably will be an ongoing requirement.
- Guarantee Requirements. Project personnel should detail the guarantee requirements of the landscape contractor. Important information includes
  - The guarantee period;
  - The survival percentages required for both herbaceous and woody plant materials;
  - The guarantee required of seeding, if any; and
  - Under what conditions the guarantee requirements will be lifted and the landscape contractor will no longer be held responsible.
- Vegetation Maintenance Requirements. If maintenance is considered part of the contract, project staff should describe any maintenance items required for vegetation (Chapter 7). Otherwise, they should include maintenance specifications in a separate maintenance contract.

5.2.5 Sediment Stabilization and Erosion Control

Staff need to prepare separate sediment stabilization and erosion control plans for the entire area of disturbance. Standard requirements and specifications for preparing these plans are generally available from state departments of transportation, state natural resources agencies, or other equivalent departments. Some states use standard specifications and requirements for sediment stabilization and erosion control developed by the SCS, so project sponsors should be sure to confirm exactly what their local and state regulations require. In addition, a National Pollutant Discharge Elimination System (NPDES) stormwater discharge permit may be required. The plan should identify any requirements for complying with permit terms.

CHAPTER 6

CONSTRUCTING THE REPLACEMENT WETLAND

6.1 OVERVIEW OF WETLAND CONSTRUCTION

Wetland replacement construction generally involves earthmoving, landscaping, erosion control, and related operations. Thus, the equipment and activities associated with wetland replacement sites are similar to those of general construction operations. The research team assumes that users of the *Guidelines* know construction from their own direct experience in highway projects and similar construction work. Therefore, the team does not address typical construction operations in detail in this chapter. The appendixes, however, contain detailed, specialized information on wetland replacement construction, including such topics as grading, substrate preparation, planting of vegetation, and water-regulating devices.

Wetland replacement construction projects require the same sound management and business procedures that typify any construction project; these are as follows:

- Inspection,
- Record keeping,
- QC,
- Change-order procedures, and
- Monitoring of contractor performance.

Most governmental agencies and private entities have formal, standardized, detailed procedures about these major construction management elements that would also apply to wetland construction; therefore, these general items are not covered in the *Guidelines*. Project sponsors should ensure that their project meets any required procedures.

The unique nature of wetland replacement construction requires that project sponsors perform the following tasks at this stage of the WRP:

- Present the critical project components at the pre-bid conference. These components are detailed in the plans and specifications for the project. Because some critical components also can increase the cost of a project, bidders need to know about them beforehand. Otherwise, they may try to economize in addressing them—to the detriment of the project. Critical components may include
  - Acceptable tolerances in final grades,
  - Special construction techniques or requirements,
  - Dewatering requirements during grading and planting, and
  - The construction timetable.
- Issue contracts only to those experienced in wetland replacement. General and landscape contractors hired for the project should have experience in successful wetland replacement projects.
- Retain at least one individual on the project with a high level of experience in successful wetland replacement. Either the project sponsor or general contractor could retain such an expert on a consulting contract to co-inspect or supervise the project with the in-house personnel.
- Reiterate the critical components of the project at the preconstruction conference. Because different company representatives may attend the pre-bid and preconstruction conferences, project sponsors should be sure to cover the same critical components at the preconstruction session so that everyone involved will be aware of the construction details essential for project success.

6.2 CONSTRUCTION MONITORING AND PLAN MODIFICATIONS

Generally, the greater the number of project personnel with wetland replacement experience, the greater the chances for project success. Therefore, project sponsors should assign personnel with experience in wetland replacement construction to oversee construction to ensure that the project proceeds according to the plans and specifications. Even if the contractors themselves have prior successful wetland replacement experience, the project sponsor's use of experienced supervisory personnel can help ensure that construction activities follow the necessary contract requirements for achieving the goals of the project.

The project sponsor's construction supervisor must approve any modifications to the original plans and specifications. Because the construction plans and specifications are considered a formal contract, any change will need to be approved by the contractor. Furthermore, the project sponsor may need to notify regulatory agencies if changes are substantially different from the plans and specifications originally approved under the permit. Such modifications may include changing grades, increasing or decreasing material

Generally, the greater the number of project personnel with wetland replacement experience, the greater the chances for project success.

quantity, and revising the landscape plans to overcome unanticipated, site-specific considerations. Finally, the construction supervisor is responsible for ensuring that approved modifications are built and that all modifications are documented clearly on the original plans and specifications.

6.3 AS-BUILT PLANS

Upon completion of construction, project sponsors and regulatory agencies need to produce the as-built plans for internal control and project records. They may also need to provide copies to regulatory agencies. If unchanged, the research team recommends that the original plans and specifications bear this label: "AS BUILT—NO MODIFICATIONS—CONSTRUCTED AS DESIGNED AND SPECIFIED."

6.4 PROBLEMS ENCOUNTERED WHEN CONSTRUCTING WETLAND REPLACEMENTS

The research team's research and experience have shown that wetland replacements have failed or only partly succeeded at this stage of the WRP because of the following:

- Incorrect or poorly presented plans and specifications, which fail to
  - Show correct tolerances associated with critical components, such as final grades and water control structures, and/or
  - Detail in the Notes and on the plans and specifications the critical project elements associated with the project;
- Failure to complete construction according to plans and specifications, because of
  - Inexperienced construction inspector and supervisors, construction contractors, and/or landscape contractors, who
    - Generally do not understand wetland replacement construction,
    - Have failed to follow the plans and specifications rigorously, or
    - Have not spent the time necessary for understanding the plans and specifications before the award of the contract;
  - Poor QC, resulting in failure to achieve tolerances for final grades, water control devices, and so forth; and
  - Personnel turnover, causing loss of project continuity and often resulting in a higher incidence of project errors.

Whatever the causes of failure, project staff may classify the problems typically encountered as either "avoidable" or "unavoidable." Avoidable problems arise from incorrect plans and specifications or from personnel errors in executing correct plans and specifications. Unavoidable errors result from problems that emerge during construction, after project completion, or both. They lie outside the control of even the most experienced wetland replacement personnel.

When addressing either avoidable or unavoidable problems, project sponsors must determine if problems are correctable, documenting their causes, if known. Documentation can add valuable data to the literature regarding successful and unsuccessful wetland replacement, thereby enhancing the chances for success on future replacement projects.

For maximum success, project sponsors should let contracts to both general and landscape contractors with experience on successful wetland replacement projects.

CHAPTER 7

MAINTAINING THE REPLACEMENT WETLAND

7.1 RESPONSIBILITIES FOR WETLAND REPLACEMENT MAINTENANCE

Maintenance is defined as all work needed to keep the wetland replacement site in the condition designated in the original or as-built construction plans and specifications. Although the research team recommends that project staff design replacement areas to be as maintenance-free as possible, project sponsors should anticipate that expected and unexpected maintenance needs will turn up during routine maintenance and during the monitoring and reporting activities. Generally, maintenance is required during the first 3 to 5 years after completion of construction. Depending on the circumstances, however, it may be required beyond this period.

The construction plans and specifications should identify the maintenance work that the general or landscape contractor will perform. If some other contractor will do the work, then project sponsors should provide that person with a maintenance manual as part of the separate maintenance contract.

The maintenance contractor or the people performing the monitoring and reporting work (Chapter 8) may identify unexpected maintenance work. They should report in detail to the project sponsor what tasks are necessary to return the site to the conditions specified. The sponsor should then schedule the repair work. Finally, the project sponsor should document the work to appropriate regulatory agencies in scheduled reports about the project (Chapter 8).

MAINTENANCE BUDGET

There will always be items of expected and unexpected maintenance. Project staff should plan a liberal maintenance budget early in the wetland replacement process.

To meet the expense of maintenance activities, the research team recommends that the project sponsor establish a liberal maintenance budget early in the WRP (e.g., to establish adequate funding before construction) to cover both expected and unexpected maintenance items. Even expected items may exceed the landscape contractor's usual guarantee requirement for the care and replacement of plants. Furthermore, because the cost of unexpected maintenance cannot be projected reliably, project sponsors should have some financial reserves to cover the cost of essential tasks. In the research team's experience, estimates for the annual maintenance budget should be roughly 2 to 3 percent of the total project budget. Failure to do the necessary maintenance work because of lack of funding could jeopardize project success and possibly violate a special condition of the wetland permit that requires such maintenance.

7.2 CATEGORIES OF MAINTENANCE ACTIVITIES

Appendix I contains detailed information about maintenance activities. The summaries below highlight four major areas of maintenance: stabilizing soils, adjusting water flow and availability, sustaining vegetation, and sustaining wildlife. Because premature conclusions about causes of and solutions for the problems can lead to costly errors and further difficulties, the research team urges that project personnel call on experts and examine wetland replacement literature to learn about the best maintenance solutions for the problems encountered. Isolating exact causes requires accurate field data about the problem and, often, conferring with experts in soils, hydrology, vegetation, animal behavior, or other areas of expertise to find the best solution.

Examples A through F, below, describe expected maintenance, while Examples G through N characterize unexpected maintenance requirements in replacement projects.

7.2.1 Stabilizing Soils

Overly steep slopes, unusual weather events, vandalism, and even animal damage may contribute to unstable soils. For example, severe erosion gullies may require project personnel to regrade the site and install stone-armored swales to convey stormwater to an appropriate discharge point. If only a few erosion gullies are present, project staff can usually solve the problem by enlarging the gullies, lining them with filter fabric, and then filling them with an appropriate size of stone to dissipate the force of water flow.

Damage from vandalism and animals may warrant the installation of exclusion devices and erecting of signs to curtail public use. These and other options can help protect soil stability in areas vulnerable to erosion.

Project staff should design replacement wetlands to be as free of maintenance as possible. Ideally, structures should require no periodic adjustments or only minor ones.

7.2.2 Adjusting Water Flow and Availability

As often may be the case, the designed wetland hydrology may not occur as planned or it may be temporarily altered. Typically, maintenance activities involving hydrology may consist of the following:

- Clearing and Repairing Water Control and Conveyance Devices. Project staff should clear blocked structures and remove debris and litter from around plants so that water flows as planned through the replacement area. Personnel should repair broken structures to restore their functions.
- Removing Animal Structures and Repairing Damage from Tunneling. Project personnel should remove beaver dams and fill in muskrat tunnels in water retention berms. Depending on the amount of damage from muskrats, project staff may have to rebuild berms.
- Building Drainage Ditches. When impounded water or poorly drained soils cause water flow and vegetation problems, one solution is to install drainage ditches to prevent impounding and to help carry excess water from the site.
- Building Stone (Riprap) Edging and Riprap Breakwaters. Project personnel can often solve the problem of

EXAMPLES OF EXPECTED MAINTENANCE IN REPLACEMENT WETLANDS

Maintenance tasks that can be expected, depending on project design and geographic location, include:

EXAMPLE A: Project staff should remove organic litter and other debris deposits throughout the vegetated areas. Such deposits will often smother vegetation or impair establishment. Generally, this work should be specified for completion during the dormant season, just before plant growth resumes. (Appendix I.3.3)

EXAMPLE B: Staff may have to replant and/or reseed to maintain the plant densities or plant survival rates specified in the construction plans and specifications or required in the special conditions of the wetland permit(s). Such replanting/reseeding is normally done during the post-growing season monitoring and reporting periods. The monitoring contractor must notify the landscape or maintenance contractor about any replanting/reseeding requirements discovered. If the work lies outside of the landscape contractor's responsibility, the maintenance budget would pay for it.

Examples of vegetation loss beyond the control of the landscape contractor include: wildlife grazing/herbivory (eating of plants), wrong hydrology or hydroperiod, drought conditions when watering was not specified, salt buildup in sediments, and vandalism. In these instances, the costs for replanting/reseeding would come from the maintenance budget.

EXAMPLE C: Watering, particularly for temporarily and seasonally flooded wetland types, should be part of the specified maintenance program. Project staff should specify watering of these wetland types for at least one full growing season during periods when soils dry throughout the root zones of the plants. During the landscape guarantee period, the cost for this maintenance would be covered in the landscape contract. The costs for watering afterward would be paid by the maintenance budget.

EXAMPLE D: When irrigation systems are used, detailed systems maintenance may be part of the construction plans and specifications or part of a separate maintenance contract's specifications. As in C, above, irrigation should continue until the plants are well established, normally for at least one full growing season.

EXAMPLE E: Staff should check all wildlife and vandal enclosures and/or control systems for their integrity. Project staff should make any necessary repairs.

EXAMPLE F: Project staff should check all water control and conveyance structures to ensure that they are functioning as designed. They should repair the damage and remove debris. Such checks and cleanings are important to keeping sediment basin loadings at a minimum.

unstable peat banks by building a stone edging in front of the bank and adding to the height of the edging as the peat bank grows. Depending on site conditions, a riprap breakwater built to 2 ft high should stabilize the peat bank for up to 50 years.

- Adjusting Existing Structures. Bulkheads, groin systems, and culverts all may cause water-flow problems. Stone armoring placed at the toes of bulkheads and other near-vertical structures helps to control the scouring of bottom sediments. Project staff can correct land erosion from wave action on the leeward side of groin structures by building a stone revetment over filter fabric on the erosion site. Finally, undersized culverts may cause water pooling and flooding. Project staff should replace them with properly sized culverts.

7.2.3 Sustaining Vegetation

Vegetation may fail or only partially establish itself for many reasons. The following describes maintenance activities for overcoming identified vegetation problems in wetland replacement areas:

- Watering or Irrigating. Unusual droughty periods and salt buildup in soils may require that project staff extensively water or irrigate the site to maintain vegetation.
- Controlling Diseases and Infestations. Project personnel must identify diseases and infestations and then determine the optimum solution for controlling them. For example, a fungus infestation (e.g., rust) can wipe out a highly susceptible species (e.g., *Spartina alterniflora*, cordgrass), if the infestation starts early in the growing season before the plants have reproduced, (i.e., produced new shoots from rhizomes). Project staff can use many products on the market, both contact and systemic, to control plant diseases and infestations.
- Eliminating Invasive Species. The degree of invasion determines, in part, what management techniques project staff should use—removal of individual plants by hand, wick application of herbicides to individual plants, or large-scale application of herbicides.
- Removing Wracks, Algal Mats, and Other Litter. Naturally occurring litter, such as wracks and algal mats, not only can obstruct water flow but can block sunlight from emerging and established plants. Project personnel should remove wracks and algal mats during regular maintenance and, depending on conditions, use algaecides as an additional control.
- Replanting and Reseeding. The conditions listed below may require that project staff replant or reseed vegetation at a replacement site. As in any maintenance activity, project staff should determine the origin of the problem before replanting or reseeding. Otherwise, the maintenance efforts may produce the same failures.
  - Salt buildup in soils. Conditioned replacement vegetation must be purchased before project staff replant the area (e.g., vegetation that is acclimated for at least 15 days before planting in more than 10 ppt salt water). Project staff should schedule replanting during periods of maximum precipitation, when soil salinity will be reduced.
  - Incorrect elevations and incorrect species. Preparers of plans must determine the proper elevations for the species required, ideally by using biological benchmarks and then replanting at those benchmark elevations. If plans and specifications list the wrong species for the area, project staff must find a replacement suitable for the existing elevations.
  - Poorly drained and oxygen-poor sediments. When plant mortalities result from these factors, project staff must achieve a balance between sediment problems and the requirements of plant species during both dormancy and growing periods. For example, cordgrass and common threesquare overwinter poorly in anoxic, poorly drained areas. Under such soil conditions, project staff may have to find substitutes for these species.
  - Non-viable seed or poor seeding techniques. If seeding fails, contractors should examine the two most common causes—low seed viability and improper seeding techniques. Once the project staff are certain of the cause and the correction, then they should draw up a reseeding schedule for the following year. Where no dependable seeding methods or viable seed sources exist, project staff may have to revegetate the area with nursery stock plants of the same species.
  - Other reasons. Many other factors affect plant mortalities, thereby necessitating replanting during maintenance. They include
    - Burning of plants by fast-release fertilizers;
    - Plants floating out of planting holes and dying;
    - Wildlife consuming the plants, either the roots or the aboveground material;
    - Poor plant quality that results in plant mortality (e.g., cut too short to have adequate stores of energy or in shipment too long);
    - Plant infestations or inadequate acclimating to wetland conditions (e.g., soil salinity or hydric soils);
    - Planting bare-root herbaceous plants too late in the growing season; and
    - Planting leafed-out, unrooted cuttings or bare-root trees and shrubs.
- Using Animal Management Techniques. Wildlife herbivority is the most severe problem in wetland replacement projects. Browsing by geese, muskrats, small rodents, rabbit, deer, and other animals on herbaceous plants, shrubs, and trees can lead to severe damage or loss of plants. Maintenance activities to prevent damage from animals may involve some of the following:

- Population reductions. When populations exceed an area's carrying capacity, project staff may manage them by trapping and removing animals from the site or by hunting. In either case, project staff will have to acquire permits and approvals for these activities from state and federal fish and wildlife departments and other applicable agencies and entities.
- Use of tree guards and fences. These products help to protect plant species from animal browsing. A number of tree-guard products work successfully. Fencing, while an effective deterrent to animals, may prove too expensive a solution. In addition, fences may conflict with some wetland replacement objectives by excluding desirable species from the area.
- Use of animal repellents. Some animal repellents may be effective in wetland replacement areas. For some products—such as Methiocarb—staff would have to obtain an experimental permit before using it at the site. (Methiocarb has proven effective in discouraging geese from foraging on grasses.) Another product proven effective on seeds and dormant and growing plant material is RO-PĖL®, which works against various animals, such as beavers, gophers, deer, rats, skunks, cattle, bears, and monkeys. (Appendix I). DEER-AWAY®, repels black- and white-tailed deer and Roosevelt elk. Liquid and powder applications last up to 2 months (Appendix I).

7.2.4 Sustaining Wildlife

Replacement projects constructed to provide habitat for threatened and endangered wildlife species may require ongoing selected trapping to remove predatory species. For example, when endangered songbird nesting habitat has been constructed as part of the wetland replacement project, trapping and removal of brown-headed cowbirds, which may parasitize the nests, may be required for the project to succeed.

EXAMPLES OF UNEXPECTED MAINTENANCE IN REPLACEMENT WETLANDS

Examples of unexpected maintenance include:

EXAMPLE G: Loss of water control because of muskrat tunneling through water retention berms. Project staff should design berms to be at least 30 feet wide at the pond level to ensure against loss of integrity because of muskrat tunneling (Smith, 1991).

EXAMPLE H: Alteration of designed hydrology by beaver dams. In cases where the altered hydrology is unacceptable, maintenance should include the trapping and relocation of beavers and the removal of dams to restore the designed hydrology.

EXAMPLE I: Intrusion into the wetland replacement site by an invasive plant species. The invasive species must be controlled by weeding (pulling), heating (use of clear plastic to cover the infested area), cutting, or applying an appropriate herbicide. (Appendix I.2.5)

EXAMPLE J: Wildlife grazing/herbivory. Staff may have to trap wildlife or secure special hunting permits to control their populations. Enclosures and other wildlife control measures may be necessary. Animal repellents are sometimes effective. (Appendix I.3.6)

EXAMPLES OF UNEXPECTED MAINTENANCE IN REPLACEMENT WETLANDS (continued)

EXAMPLE K: Erosion of banks or channels leading into or out of the replacement wetland. Staff may have to regrade or to build stone armoring to prevent recurrence of the problem. (Appendix I.2.2)

EXAMPLE L: Vandalism of the site or creation of dirt bike trails. Such problems require that staff post signs or enlist other means to restrict access to area. Vandalism may require replanting and structural repairs. (Appendix I.3.5)

EXAMPLE M: Loss of vegetation because of disease or insect infestation. Once project staff identify the disease or insect, they can use an appropriate pesticide to control the problem. For example, most broad range systemic and contact fungicides are effective against leaf spot and rust infestations. (Appendix I.3.4)

EXAMPLE N: The removal of plants and damage of structures or grades by ice. Replanting and repair of damage will be necessary. (Appendix I.3.2)

7.3 CONCLUSION

The maintenance needs of a wetland replacement site vary with the type of replacement and with the unique events and circumstances that characterize any project. Whether a salt marsh or a forested wetland, replacement projects all share one characteristic: their success depends in part on important maintenance tasks being performed on schedule so that any discrepancy between existing conditions at the site and conditions specified in the plans and specifications can be analyzed and corrected. Wetland replacements can fail from single or multiple causes: proper maintenance and monitoring ensure that a project will have the best possible opportunity for success.

CHAPTER 8

MONITORING THE REPLACEMENT WETLAND AND REPORTING

8.1 OVERVIEW OF MONITORING ISSUES

Monitoring and reporting is an important step in the WRP. Project sponsors use the data and information collected during postconstruction monitoring to assess if the replacement wetland is achieving its functional goals and objectives as established in Step 1 of the WRP and to identify any maintenance requirements. The information also is used to document compliance with the permit and to keep the regulatory agencies and project sponsors informed about the site's status.

MONITORING SUCCESS

Through monitoring, project staff can determine the success of the replacement wetland.

Monitoring activities involve qualitative and quantitative evaluations to assess the biological, physical, and hydrologic characteristics of the constructed replacement wetland. While there is consensus that monitoring is essential, there is a lack of consensus about what monitoring should entail (i.e., what approach is necessary to evaluate relative success and what should be measured) (Kusler and Kentula, 1990).

Many researchers suggest monitoring should compare—by qualitative and quantitative sampling of the vegetation, benthos, soil chemistry, and so forth—the replacement wetland with a natural reference wetland of the same type (Kentula et al., 1992; Erwin, 1991; Pacific Estuarine Research Laboratory, 1990; Horner and Raedeke, 1989; and White et al., 1989). The research team believes this approach has the following significant drawbacks:

- Wetlands are complex systems; probably no two wetlands are equivalent in all aspects. Therefore, attempting to find and to use a reference wetland to measure success is difficult, time-consuming, and usually extremely costly. One possible exception to this may be the salt marshes of the East Coast because of their low vegetative diversity.
- The approach assumes, without justification, that old natural wetlands are the "ultimate" in providing wetland functions and that young natural wetlands, which inevitably are developing on mineral soils, are inferior in this regard. This assumption can be challenged because of the following:
  - Replacement wetlands will often be constructed on uplands graded to suitable elevations for sustaining wetlands; their mineral soils will be different from the high organic or peaty soils of old natural wetlands. Therefore, old natural wetlands are not appropriate comparative references for replacement wetlands: differences in soils will lead to predictable differences in benthic communities, microbial communities, soil chemistry processes, water quality control functions, vegetation productivity, and wildlife use.
  - Young natural wetlands developing on mineral soils similar to those of a replacement wetland would be more appropriate references, but even they would not serve as fair comparisons because no two wetlands will be equivalent in all regards.
  - Wetlands are constantly changing systems. Consequently, evaluators may reach erroneous conclusions when they attempt to compare an old changing wetland with a young changing one.
  - The scientific delineation of wetlands does not distinguish between old wetlands with organic soils and young wetlands with mineral soils.

Because of these drawbacks, the team recommends (as discussed in Section 1.4.2) that a reference wetland be used only as a guide to establish replacement goals and objectives for out-of-kind replacement projects and for identifying composition and density of the target species at the replacement site.

Project sponsors may be required to use approaches not involving a reference wetland but requiring detailed quantitative sampling of vegetation and soils and extensive hydrologic monitoring and water quality sampling of the replacement site. On the basis of the experiences of the research team, these approaches are time-consuming and costly and, in the team's opinion, not a practical way to assess if the project has achieved its functional goals and objectives. While such approaches involve studies that, if properly designed, may yield important scientific information about the constructed wetland, without comparative studies, the data may have limited importance.

If *Guidelines* users are required, or elect, to use a comparative wetland monitoring approach, to perform detailed monitoring studies, or both, they may use one of many monitoring protocols detailed elsewhere (not included in the *Guidelines*). Project sponsors always should check with the regulatory agencies and local wetland experts about the preferred monitoring protocols.

8.2 THE RECOMMENDED WRP MONITORING APPROACH AND CRITERIA FOR SUCCESSFUL REPLACEMENT

8.2.1 Overview of the Approach

The project sponsor must document both success and problems (i.e., disparities between the replacement wetland and the plans), as discussed in Section 8.2.2, during the monitoring period set by the permit. To do so, the research team recommends that the monitoring approach compare over time the existing as-built replacement wetland with the original or as-built construction plans and specifications (Garbisch, 1989a and b). The researchers believe that if (1) the replacement wetland persists in comparing favorably with the original or as-built plans and specifications during the monitoring period—with allowances for natural succession and natural variability—and if (2) the plan preparations followed the WRP procedures, then the wetland will replace lost chemical, physical, and biological wetland functions and achieve the project goals and objectives over time. In the team's experience, regulatory agencies and project sponsors are likely to consider the wetland replacement project a success.

DETERMINING PROJECT SUCCESS

If the replacement wetland agrees with the original or modified construction plans over time, then the project is successful in achieving its goals and objectives.

If the design elements relating to the desired function(s) are provided, then the function(s) and the project goals and objectives are provided. No further study is necessary.

The research team believes the recommended monitoring approach has the following advantages:

- The replacement wetland is compared to the plans, not to a reference wetland. This eliminates the inherent problems—previously described—associated with finding a reference wetland.
- The strategy gives the project sponsor and the regulatory agencies guidance and criteria as to what defines success. If the site is constructed, the hydrology is correctly established, the plant material is present—all according to the plans—and the wetland persists over time, the replacement wetland probably will achieve its goals and objectives, and the project will be successful, in the opinion of the research team.
- Collecting costly and confusing data pertaining to diverse wetland components (e.g., soils, algae, benthos, and wildlife) becomes unnecessary. The monitoring becomes simplified, and project staff and others can easily assess the data.

8.2.2 Recommended Approach and Reporting

The research team recommends the following procedure for documenting the results of comparisons of the replacement wetland with the original or modified plans:

- Photograph the wetland from a sufficient number of locations and at regular intervals in order to create a complete visual record of the site conditions.
- Prepare a photographic key using the original or modified plans. Show directly on the plan mylars the location of the photographed sites, along with the aboveground heights and directions (arrows).
- At each reporting period, submit a set of these plans with photographs and descriptive comments. If different persons are photographing the site, be sure that they take the pictures each time from permanent photograph posts to ensure the same height, direction, and location to keep the successive photographs comparable.

This information becomes the basis for the monitoring report required in the special conditions of wetland permits to keep the regulatory agencies informed about the status and relative success of the project. Reporting also may be a requirement of the project sponsor for project management and control. The report should

- By the method described above, document the comparison between the replacement wetland and the original or modified plans;
- Discuss favorable comparisons and acceptable differences between the replacement wetland and the original or modified plans and include photographs and plans to

support the discussion (see examples provided below); and
- Discuss any unacceptable differences that arise from the comparison and whether or not it is possible to bring the differences into agreement with the plans and specifications (including both photographs and plans). (When possible, discuss maintenance and a proposed maintenance schedule. If it is not possible to bring the out-of-specification condition into compliance with the plan, then discuss alternative strategies to salvage the project that would make it partially successful.)

Missing from this procedure is any quantitative sampling of the wetland. The research team's experience indicates that project sponsors may be required to conduct sampling to confirm success of the plantings at the site. Researchers have observed a tendency for regulatory agencies to require applicants to achieve a certain level of success rate for plantings relative to both survivability (e.g., 70 to 85 percent) of the plantings and overall success measured by aerial cover by vegetation in areas shown on the plans (e.g., 75 to 85 percent). Members have also observed requirements for species inventory (e.g., plants and birds). Collecting these data may be useful if they help verify whether or not the site achieves the functional goals and objectives for the replacement site. The researchers also believe that these numerical criteria can be misinterpreted and misused unless provisions, noted earlier, allow for acceptable differences (in terms of natural succession and natural variability). The EPW (Appendix J) also may be used as a tool—or other locally acceptable assessment procedures may be used—during monitoring to confirm if the replacement wetland has achieved its functional goals and objectives. The results can then be submitted to the regulatory agencies with the recommended monitoring report to verify conformance with the established goals and objectives.

8.3 ACCEPTABLE DISPARITIES BETWEEN THE REPLACEMENT WETLAND AND THE PLANS AND SPECIFICATIONS

Wetlands are not static systems. Certain disparities between the replacement site and the original or modified construction plans may be allowable. For example, the plans may state that a preponderance (i.e., more than or equal to 75 percent coverage) of herbaceous plants should be present in all areas on the plans that show vegetation. If species prosper that are different from those planned but are not undesirable or invasive, however, they are acceptable. For example, where construction plans and specifications require woody or herbaceous species for specific reasons—such as for wildlife food and cover—project staff must note this clearly on the plans. In such a case, these species must be present to the extent required in the plans and specifications or in the special conditions of the wetland permit.

8.4 RATIONALE FOR THE RECOMMENDED MONITORING APPROACH

The proposed monitoring approach assumes technically sound construction plans and specifications have been prepared and that the wetland has been constructed according to them. Thus, project sponsors must emphasize the following requirements of the WRP:

- Establish clear and concise goals and objectives for replacing functions (Step 1);

EXAMPLES OF ACCEPTABLE DISPARITIES BETWEEN REPLACEMENT WETLAND AND PLANS AND SPECIFICATIONS

In the following examples, disparities between the replacement wetland and the plans and specifications arise because of a lapse of time. Because all wetlands continuously change, this kind of disparity is acceptable.

EXAMPLE A: Sea level rise will lead to hydroperiod changes for the vegetation zones in tidal coastal, estuarine, and riverine wetlands where peat bank development (rise) is occurring at a slower or faster rate. As a result, vegetation will change to be compatible with the change in hydroperiod (Appendix I.2.16).

EXAMPLE B: Even though the pool level in a nontidal marsh is constant, the depth of water to the marsh surface may decrease with time because of peat formation. This decrease will lead to new wetland plant species that will tolerate the shallower water and, possibly, to the disappearance of the specified species (Appendix I.2.16).

EXAMPLE C: Over a 10-year period, a cattail marsh gradually converted to a monotypic arrow arum marsh. Muskrats were "eating out" the cattail rhizomes and destroying the peat structure of the cattail marsh, leaving behind an unconsolidated organic soup as a substrate. Cattail will not regenerate in such sediments, whereas arrow arum will (see Appendix I.2.15).

The recommended monitoring approach depends on project staff preparing technically sound construction plans and specifications and then building the wetland according to them.

- Carefully select the wetland replacement site (Steps 2 and 3);
- Achieve a reliable, predictable design for establishing wetland hydrology (Steps 3, 4, and 5);
- Prepare detailed, accurate plans and specifications (Step 5);
- Ensure that the approved construction plans and specifications are followed during construction and that any revisions to the plans are documented (Step 6); and
- Undertake preventive maintenance to avoid problems that could jeopardize project success (Step 7).

The research team also assumes the following about its recommended monitoring approach: if the literature-validated design elements in Appendix J—or another wetland functional evaluation procedure—are used in the replacement design to provide desired functions, and if the project staff determine that these design elements are found to be in place after construction, the project goals and objectives probably will be met.

Accepting this monitoring approach places more of an initial burden on the project staff and on the project sponsor's regulatory agency's review and approval processes than some other approaches. Everyone needs to make informed, accurate decisions at every step. In the experience of the research team, the WRP ultimately establishes a practical framework and procedure for completing successful wetland replacement projects. Furthermore, the team believes that the WRP will reduce the problems encountered in constructing replacement wetlands and the liability placed on project sponsors who must comply with permit requirements for replacement of lost wetland functions. Project sponsors must be mindful that success will not always be achieved. The applied science of wetland creation or restoration is still developing (Introduction); problems can be expected to occur (Chapters 6 and 7 and Appendix J). On the basis of the experience and the research findings of the team, however, following the WRP can reduce those problems and help achieve successful wetland replacement.

REFERENCES

Adamus, P. R., Clairain, E. J., Smith, R. D., and Young, R. E. *Wetland Evaluation Technique (WET), Volume II: Methodology.* Department of the Army, Waterways Experiment Station, Vicksburg, Mississippi (1987).

Adamus, P. R., Smith, R. D., and Muir, T. A. *Manual for the Assessment of Bottomland Hardwood Functions.* U.S. Environmental Protection Agency, Office of Wetlands Protection, Washington, D.C. (1990).

Ammann, A. P., Franzen, R. W., and Johnson, J. L. Method for the evaluation of inland wetlands in Connecticut. *DEP Bulletin No. 9.* Connecticut Department of Environmental Protection, Hartford, Connecticut (1986).

Ammann, A. P. and Stone, A. L. Method for the comparative evaluation of nontidal wetlands in New Hampshire. *NHDES-WRD-1991-3.* New Hampshire Department of Environmental Services, Concord, New Hampshire (1991).

Bartoldus, C. C., Garbisch, E. W., and Kraus, M. L. *Evaluation for Planned Wetlands.* Environmental Concern, Inc., St. Michaels, Maryland (1994) 327 pp (not including appendixes).

Bradshaw, J. G. A technique for the Functional Assessment of Nontidal Wetlands in the Coastal Plain of Virginia. *Applied Marine Science and Ocean Engineering, Special Report No. 315.* Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia (1991) 31 pp. (not including appendixes).

Brinson, M. M. "A Hydrogeomorphic Classification for Wetlands." Technical Report WRP-DE-R. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi (1993) 101 pp.

Brinson, M. M., Hauer, R., Lee, L. C., Nutter, W. L., Rheinardt, R., Smith, R. D., and Whigham, D. F. *Guidebook for Application of Hydrogeomorphic Assessment to Riverine Wetlands.* Wetland Research Program TR-WRP-DE, U.S. Army Engineer Waterways Experiment Station, Vicksbury, Mississippi (1995) (in press)

Cable, T. T., Brack, Jr., V., and Holmes, V. R. Simplified method for wetland habitat assessment. *Environmental Management,* Vol 13, No. 2 (1989) pp. 207–213.

Cook, R. A., Lindley Stone, A. J., and Ammann, A. P. *Method for the Evaluation and Inventory of Vegetated Tidal Marshes in New Hampshire (Coastal Method).* Audubon Society of New Hampshire, Concord, New Hampshire (1993) 77 pp. (not including appendixes).

Driscoll, E. D., Shelley, P. E., and Strecker, E. W. "Analytical Investigation of Pollutant Loadings and Impacts from Highway Stormwater Runoff+Research Report." *FHWA-RD-88-008.* Federal Highway Administration, Washington, D.C. (1988).

Environmental Laboratory. *Corps of Engineers Wetland Delineation Manual, Technical Report Y-87-1.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi (1987).

Environmental Work Group. "Coastal Wetland Planning, Protection, and Restoration Act: Wetland Value Assessment Methodology and Community Models." U.S. Fish and Wildlife Service, Lafayette, Louisiana (1994) 16 pp. (not including appendixes).

Erwin, K. L. "Wetland evaluation for restoration and creation." In *Wetland Creation and Restoration: The Status of the Science, Vol. II: Perspectives, EPA/600/3-89/038b,* J. Kusler and M. E. Kentula (Eds.). Environmental Research Laboratory, Corvallis, Oregon (1991) pp. 15–45.

Euler, D. L., Carreiro, J. F. T., McCullough, G. B., Snell, E. A., Glooschenko, V., and Spurr, R. H. *An Evaluation System for Wetlands of Ontario, South of the Precambrian Shield (Second edition).* Ontario Ministry of Natural Resources and Environment Canada, Ontario, Canada, (1984) 169 pp.

Garbisch, E. W. "Information Needs in the Planning Process for Wetland Creation and Restoration." *Wetland Creation and Restoration: The Status of the Science. Vol II: Perspectives. EPA/600/3-89/38b,* J. Kusler and M. E. Kentula (Eds.). Environmental Research Laboratory, Corvallis, Oregon (1989a) pp. 9–13d.

Garbisch, E. W. "Wetland Enhancement, Restoration, and Construction." *Wetlands Ecology and Conservation: Emphasis in Pennsylvania.* S. K. Majumdar, R. P. Brooks, F. J. Breener, and R. W. Tiner, Jr, (Eds.). The Pennsylvania Academy of Science (1989b) 395 pp.

Golet, F. C. "Classification evaluation of freshwater wetlands as wildlife habitat in the glaciated northeast." Transactions of the Northeast Fish and Wildlife Conference, Vol. 30 (1973) pp. 257–279.

Gray, D. H. and Leiser, A. T. *Biotechnical Slope Protection and Erosion Control.* Van Nostrand Reinhold Company, New York, New York (1982) 271 pp.

Gupta, M. K. Constituents of Highway Runoff, Vol. VI: Executive Summary. *FHWA/RD081/047.* Federal Highway Administration, Washington, D.C. (1981).

Hammer, D. A. *Constructed Wetlands for Wastewater Treatment.* Lewis Publishing, Chelsea, Michigan (1989).

Harris, J. L. and Lindstrom, C. E. *Analysis of Highway Runoff for Interstate 30,* Little Rock, Arkansas, Demonstration Project No. 56. Arkansas State Highway and Transportation Department, Little Rock, Arkansas (1985).

Hollands, G. H. and McGee, D. W. A Method for Assessing the Functions of Wetlands, *Proceedings of the National Wetlands Assessment Symposium,* J. A. Kusler (Ed.). Association of State Wetland Managers, Berne, New York (1985) pp. 108–118.

Horner, R. R. and Raedeke, K. J. Guide for Wetland Mitigation Project Monitoring. *Report No. WA-RD 195.1.* Washington State Department of Transportation, Olympia, Washington, (1989) 265 pp.

Hunter, C. J. *Better Trout Habitat: A Guide to Stream Restoration and Management.* Island Press, Washington, D.C. (1991) 318 pp.

Kentula, M. E., Brooks, R. P., Gwin, S. E., Holland, C. C., Sherman, A. D., and Sifneos, J. C. An Approach to Improving Decision Making in Wetland Restoration and Creation. A. J. Hairston (Ed.) For the U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon. Island Press, Washington, D.C. (1992) 151 pp.

Kobriger, N. P. Sources and Migration of Highway Runoff Pollutants, Vol. I., *FHWA/RD-84/057.* Federal Highway Administration, Washington, D.C. (1984).

Kramme, A. D., Rolan, R. G. and Smith, L. A. Reference Manual for Assessing Water Quality Impacts from Highway Maintenance Practices Vol. III. Federal Highway Administration, Washington, D.C. (1985).

Kress, S. W. *The Audubon Society Guide to Attracting Birds.* Charles Scribner's Sons, New York, New York (1985) 377 pp.

Kusler, J. A. and Kentula, M. E. (Eds.). *Wetland Creation and Restoration: The Status of the Science. Volume I: Regional Reviews. Volume II: Perspectives. EPA/600/3-89/038b.* Environmental Research Laboratory, Corvallis, Oregon (1990) 473 and 172 pp.

Larson, J. S. (Ed.). "Models For Assessment of Freshwater Wetlands." *Publication No. 32.* Water Resources Research Center, University of Massachusetts, Amherst, Massachusetts (1976) 91 pp.

Lonard, R. I., Clairain, Jr., E. J., Huffman, R. T., Hardy, J. W., Brown, L. D., Ballard, P. E., and Watts, J. W. Analysis of Methodologies Used for the Assessment of Wetlands Values. Final Report. Prepared by Environmental Laboratory, U.S. Army Corps of Engineers, Waterways Experiment Station, for U.S. Water Resources Council, Washington, D.C. (1981) Variously paginated with appendixes.

Lonard, R. I., Clairain, Jr., E. J., Huffman, R. T., Hardy, J. W., Brown, L. D., Ballard, P. E., and Watts, J. W. "Analysis of Methodologies for Assessing Wetlands Values." *Technical Report Y-83-2.* U.S. Army Engineer Waterways Experiment Station, U.S. Water Resources Council, Washington, D.C. (1984).

Mar, B. W., Horner, R. R., Ferguson, J., Spyridakis, D. E., and Welch, E. B. Summary, Washington State Highway Runoff Water Quality Study 1977+1982. Prepared for the Washington State Department of Transportation. Department of Civil Engineering, University of Washington, Seattle, Washington (1982).

Marble, A. D. A Guide to Wetland Functional Design. *Report No. FHWA-IP-90-101.* U.S. Department of Transportation, Federal Highway Administration, McLean, Virginia (1990) 222 pp.

Minnesota Board of Water and Soil Resources. *Minnesota Routine Assessment Methodfor Evaluating Wetland Functions (MNRAM, Draft Version).* St. Paul, Minnesota (1995) 27 pp.

Moxness, K. L. Characteristics of Urban Freeway Runoff. *Report No. FHWA/MN-86/02.* Minnesota Department of Transportation, St. Paul, Minnesota (1986).

North Carolina Department of Environment, Health, and Natural Resources (NCDEHNR). Guidance for Rating the Values of Wetlands in North Carolina. Fourth version. Report No. 95-01. NCDEHNR, Division of Environmental Management Water Quality Section (1995) 57 pp.

Pacific Estuarine Research Laboratory. *A Manual For Assessing Restored and Natural Coastal Wetlands With Examples From Southern California.* Biology Department, San Diego State University, San Diego, California (1990) 105 pp.

Pierce, G. J. Planning Hydrology for Constructed Wetlands. WTI 93-2. Wetland Training Institute, Poolesville, Maryland (1993) 49 pp.

Racin, J. A., Howell, R. B., Winters, G. R., and Shirley, E. C. *Report No. FHWA/CA/TL-82/11.* California Department of Transportation, Sacramento, California (1982).

Reppert, R. T., Sigleo, W., Stakhiv, E., Messman, L., and Meyers, C. "Wetland Values, Concepts and Methods for Wetlands Evaluation." IWR Research Report 79-R1. U.S. Army Corps of Engineers, Institute for Water Resources, Springfield, Virginia (1979).

Roth, E., Olsen, R., Snow, P., and Summer, R. Oregon Freshwater Wetland Assessment Methodology. Oregon Division of State Lands, Salem, Oregon (1993) 178 pp.

Schueler, T. R. *Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetlands in the Mid-Atlantic Region.* Metropolitan Washington Council of Governments, Washington, D.C. (1992).

Smith, R. D., Ammann, A., Bartoldus, C., and Brinson, M. M. An Approach for Assessing Wetland Functions Using Hydrogeomorphic Classification, Reference Wetlands, and Functional Indices, Wetland Research Program Technical Reference Wetlands, and Functional Indices. Wetland Research Program Technical Report WRP-DE-9, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi (in press).

U.S. Army Corps of Engineers. *The Highway Methodology Workbook Supplement: Wetlands Functions and Values, A Descriptive Approach. NEDEP-360-1-30a.* New England Division. Massachusetts (1995) 32 pp.

U.S. Army Corps of Engineers and the Minnesota Environmental Quality Board. The Minnesota Wetland Evaluation Methodology for the North Central United States. U.S. Army Corps of Engineers, St. Paul District, Minnesota (1988) 97 pp. (not including appendixes).

U.S. Environmental Protection Agency. Design Manual, Onsite Wastewater Treatment and Disposal Systems. EPA 625/1-80-012. U.S. Environmental Protection Agency. Municipal Environmental Research Laboratory (1980) 41 pp.

U.S. Environmental Protection Agency. Technical Report: Literature review of wetland evaluation methodologies. U.S. Environmental Protection Agency, Region V, Chicago, Illinois (1984) 120 pp. (not including appendixes).

U.S. Environmental Protection Agency. Water Quality Standards for Wetlands: National Guidance. EPA 440/S-90-011. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, D.C. (1990) 34 pp. (not including appendixes).

U.S. Fish and Wildlife Service. Habitat Evaluation Procedures (HEP) Manual (102 ESM), Washington, D.C. (1980) Paginated variously.

Versar and Camp Dresser & McKee. Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff. *Report No. FHWA-RD-87-056.* Federal Highway Administration, Washington, D.C. (1988).

Welling, C. H., Pederson, R. L., and van der Valk, A. G. "Recruitment for the Seed Bank and the Development of Zonation of Emergent Vegetation During Drawdown in a Prairie Wetland. *Journal of Ecology*, Vol 76, (1988) pp. 483–496.

White, T. A., Allen, J. A., Mader, S. F., Mengel, D. L., Perison, D. M., and Tew, D. T. (Eds.). MiST: A Methodology to Classify Pre-project Mitigation Sites and Develop Performance Standards for Construction and Restoration of Forested Wetlands. Performed for Region IV, U.S. Environmental Protection Agency, Atlanta, Georgia. North Carolina State University, Raleigh, North Carolina (1989) 85 pp.

ACRONYMS

ATV	All-terrain vehicle
BMP	Best management practice
CMP	Corrugated metal pipe
COE	U.S. Army Corps of Engineers
EA	Environmental assessment
EDIS	Environmental Data and Information Source
EIS	Environmental impact statement
EPA	Environmental Protection Agency
EPW	Evaluation for Planned Wetlands
FAC	Facultative
FACW	Facultative wetland
FAV	Floating aquatic vegetation
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FWS	Fish and Wildlife Service
FIRM	Flood Insurance Rate Map
HEP	Habitat Evaluation Procedure
HGM	Hydrogeomorphic
KeA	Keyport silt loam
MHW	Mean high water
MHHW	Mean high high water
MLLW	Mean low low water
MLW	Mean low water
NCDC	National Climatic Data Center
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NWI	National Wetland Inventory
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OC	On-center planting
pls	Pure live seed
ppt	Parts per thousand
QA/QC	Quality assurance and quality control
SAV	Submerged aquatic vegetation
SCS	Soil Conservation Service
SER	Society of Ecological Restoration
SHA	State highway agency
U.S. EPA	United States Environmental Protection Agency
U.S. FWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
WATSTORE	Water Data Storage and Retrieval System
WET	Wetland Evaluation Technique
WRP	Wetland replacement process
WSEL	Water Surface Elevation

GLOSSARY

Access—A factor to be considered when selecting a wetland mitigation site. The scientists and laborers working on the wetland as well as any equipment and vehicles will need to be able to get onto the site.

Acreage requirements—The amount of land needed for a replacement wetland project. The total number of acres depends on the design objectives, the site's physical features, and the regulatory requirements for upland buffers around the replacement wetland.

Algae—Rootless, stemless, leafless plants containing chlorophyll. They may be one-celled, colonial, or filamentous.

Anoxic/anoxia—A level of oxygen too low to support living organisms. Oxygen dissolved in water may become bound by chemical contaminants or used up by microorganisms, such as algae, when other nutrients such as nitrogen and phosphorous are present in excess. Or, sedimentation may block sunlight from reaching submerged green plants, thereby inhibiting the production of oxygen in the first place.

Armoring—From the term armed" in reference to plants; equipped with sharp-pointed modified stems, leaves or epidermal outgrowths.

As-built plans—The final plans and specifications to be submitted to project sponsors and regulatory agencies upon completion of the construction of a replacement wetland.

Assimilative capacity—The total quantity of a material (such as sediments, nutrients, or toxic contaminants) that a wetland (or other ecosystem) can remove through filtration, transformation, retention, or other physical, chemical, or biological mechanism.

Avoidance—when used in the context of wetland management, the prevention of the loss of wetland area or function by implementing regulations or management strategies to protect wetlands.

Baseflow (Also called dry-weather flow)—In a stream or river, the flow of water derived from the seepage of groundwater and/or through-flow into the surface watercourse. At times of peak river flow, baseflow forms only a small proportion of the total flow, but in periods of drought it may represent nearly 100 percent, often allowing a stream or river to flow even when no rain has fallen for some time.

Baseline monitoring—Periodic measurements or observations of ecosystem attributes over time to assess trends in ecosystem conditions and to identify new environmental problems as they arise.

Bedrock—The solid rock underlying soils and the mantlerock in depths ranging from zero (where exposed by erosion) to several hundred feet.

Benchmark (Biological benchmark)—One or more plant species at a given elevation that, for decades or longer, has been associated with and supported by hydrologic conditions adjacent to and proposed for use at the wetland replacement site. Biological benchmarks reflect seasonal water level changes (in lakes, rivers, and streams), tidal elevations (normal tidal range, spring tidal range, mean high water), and seasonal water salinities.

Berms—A ridge or nearly flat platform at the rear of a beach (or lake edge) and standing just above the mean high-water mark. Its distinguishing feature is a marked break of slope at the seaward (or water's) edge.

Bioaccumulation—The process by which a compound is taken up and concentrated by an organism, both from the surrounding media (water, soil, or air) and through the food chain.

Biocriteria or biological criteria—Numerical values or narrative expressions that describe the biological integrity of aquatic communities inhabiting or relying on wetlands of a given designated use and the habitat and hydrological conditions necessary to sustain that use. Biological criteria are considered to be a subset of water quality criteria.

Buffer—An upland area surrounding the replacement wetland that is set aside and designated as an area to be left alone to protect the wetland. Acreage size will depend on regulatory requirements. A buffer area can contribute runoff to the site, protect from off-site pollutants, and ensure the success of the replacement wetland. Established buffers can at least partially filter pollutants and sediments from overland and subsurface flow thereby decreasing the input of these contaminants into the ecosystem.

Clay—A soil textural class consisting of mineral particles less than .002 mm in diameter. It is a fine-grained soil that has a high plasticity index in relation to the liquid limits.

Conceptual plan/conceptual wetland replacement plan—Provides a qualitative overview of the wetland replacement and verifies to the project sponsor and regulatory personnel that the goals and objectives of the project have been realized.

Constructed wetland—A wetland that has been created or restored specifically to treat either point or nonpoint source pollution wastewater.

Contours—Imaginary lines of constant elevation on the ground surface. The corresponding printed line on a map is called a contour line.

Conversion—The transformation of a wetland into a different land cover or land use (e.g., filling in a wetland for building construction), resulting in the complete or near complete loss of the original wetland functions.

Creation—The conversion of a persistent non-wetland area into a wetland through some activity of man. Artificial wetlands, as from irrigation or weeding, revert to their original habitat type. Human-induced created wetlands, as from earthmoving or dam-building, do not revert but persist.

Created wetland—A wetland that has been constructed on a non-wetland site specifically to compensate for wetland losses permitted under Section 404 of the Clean Water Act.

Culverts—Short, closed conduits through which water flows.

Cumulative effects—the net change in the overall landscape function that results from cumulative impacts.

Cumulative impacts—the sum of all the impacts that have occurred over a project area's entire landscape over time.

Deicing salts (Pollutants)—Sodium chloride (NaCl), the principal deicing agent used on highways in the northern states, can cause problems due mostly to the chloride: high levels can stress freshwater plants. In particular, many seedlings, shoots, and plugs may be especially sensitive to deicing salts. Underground plant structures such as rhizomes and tubers are also sensitive to salt.

Degradation—The loss of function (in this case, wetland or landscape functions) resulting from exposure to a stressor, or stressing agent, such as deicing salts. Wetland degradation would include direct and indirect effects resulting from the addition of harmful agents and/or the removal of beneficial factors (e.g. damage to the environmental infrastructure that maintains a wetland as a result of hydrological modifications caused by dam construction or stream diversion).

Denitrification—Biologically mediated reduction of nitrate to gaseous forms of nitrogen (NO, N_2O, and N_2). Nitrate is used as an electron acceptor in the absence of free oxygen (e.g., in wetland soils and sediments); denitrification occurs in association with the decomposition of organic matter.

Design features—The details specified to construct the replacement wetland (e.g., acreage and side slope specifications).

Dewatering requirements—The removal of groundwater to reduce flow-rate or diminish pressure. Dewatering is usually undertaken to improve conditions in surface excavations and to help construction work at or near the surface. Depending on various hydrological conditions, water is removed by extraction from wells, electroosmosis, sumps and drains, and vertical drains, or excluded by grouting, compressed air, or freezing techniques.

Dissolved oxygen (level)—The concentration of oxygen held in solution in water. Usually it is measured in mg/l or expressed as a percentage of the saturation value for a given water temperature. The solubility of oxygen varies inversely with temperature; this is important, because the warmer the water the larger the proportion of dissolved oxygen that is used by poikilotherms (cold-blooded organisms). The dissolved oxygen level is an important indicator of water quality. In general, oxygen levels decline as pollution increases.

Drainage area (Drainage basin)—An area bounded by drainage divides, defined with respect to a point along a stream. All the runoff generated within the areas passes the point along the stream; runoff generated outside the basin does not pass that point.

Drawdown—The gradual reduction in water level in a (stormwater) wetland due to the combined effect of infiltration and evaporation. Also refers to as the deliberate extraction of groundwater.

Drought—A period during which rainfall is either totally absent or substantially lower than usual for the area in question, so that there is a resulting shortage of water for human use, agriculture, or natural vegetation and fauna.

Ecoregion—Ecoregions are mapped geographic areas that have relatively homogeneous ecological systems and homogeneous relationships among organisms and their environment.

Ecosystem—A complex of biological communities and the physical and chemical environment forming a functioning whole in nature. Wetlands, upland forests, lakes, and streams are examples of types of ecosystems.

Effect—A change in wetland structure and/or function in response to some causal agent, such as a constructed dam or biochemical pollutant.

Effectiveness elements—Specific factors that assess the capability of a wetland to perform a function due to its physical, chemical, and biological attributes. Effectiveness does not estimate the magnitude at which a function is performed, only the probability that a wetland will perform the function.

Emergent plant communities—Erect, rooted, herbaceous vegetation, excluding mosses and lichens.

Enhancement—The increase in one or more values of all or a portion of an existing wetland by man's activities, often with the accompanying decline in other wetland values. The intentional alteration of an existing wetland to provide conditions that previously did not exist and that, by consensus, increase one or more values is enhancement. Enhancement and restoration are often confused. For example, the diking of emergent wetlands to create persistent open-water duck habitat with the consequent loss of its brown shrimp nursery habitat illustrates the potential for conflict.

Erosion—Soil erosion is the part of the overall process of denudation that includes the physical breaking down, chemical dissolving, and transportation of material by agents such as water, wind, ice, and gravity.

Estuarine marsh—Tidal wetlands usually semi-enclosed by land but with partly obstructed or sporadic access to the open ocean. Salinities are usually greater than 0.5 parts per thousand.

Estuary—A coastal body of water that has a free connection with the open sea and where fresh water, derived from land drainage, is mixed with sea water. Normally an estuary is the result of valley drowning by the postglacial rise in sea level. The action of tidal currents on the large amount of available sediment may give rise to a range of mobile bottom forms including ebb and flood channels, sandbanks, and sand waves.

Eutrophication—The process of nutrient enrichment (usually by nitrates and phosphates) in aquatic ecosystems, such that the productivity of the system ceases to be limited by the availability of nutrients. The rapid increase in nutrient levels stimulates algal blooms. On death, bacterial decomposition of the excess algae may deplete oxygen levels seriously. The extremely low oxygen concentrations that result may lead to the death of fish, creating a further oxygen demand, and so leading to further deaths.

Evaporation—The physical transformation of water from liquid to vapor state.

Evapotranspiration—A combined term for water lost as vapor from a soil or open water surface (evaporation) and water lost from the surface of a plant mainly via the stomata (transpiration). The combined term is used since in practice it is very difficult to distinguish which of these two sources contributes water vapor in water-balance and atmospheric studies.

Exotic species—A species found in but not native to a particular area.

Facultative species—Species that can occur in both wetlands and uplands; there are three subcategories of facultative species: (1) *facultative wetland plants* (FACW) that usually occur in wetlands (estimated probability 67 to 99 percent) but occasionally found in non-wetlands, (2) *facultative plants* (FAC) that are equally likely to occur in wetlands or non-wetlands (estimated probability 34 to 66 percent), and (3) *facultative upland plants* (FACU) that usually occur in non-wetlands (estimated probability 67 to 99 percent) but occasionally are found in wetlands (estimated probability 1 to 33 percent).

Federal Emergency Management Agency (FEMA) maps—These maps delineate the 100-year flood elevations for most regions of the country. They have limited use in situating wetland replacement projects but may have some value in identifying flood-prone areas under consideration as replacement sites. FEMA also has flood studies for certain watersheds; where available, such studies may be useful in estimating floodflows and elevations.

Fetch—The maximum open water distance unimpeded by intersecting islands, erect vegetation, or other obstructions.

Fish—Broadly speaking, any poikilothermic (cold-blooded), legless, aquatic vertebrate that possesses a series of gills on each side of the pharynx, a two-chambered heart, no internal nostrils, and at least a median fin as well as a tail fin. If the lampreys and hagfish (*Agnatha*) are excluded, this definition includes the sharks and rays (*Chondrichthyes*), in which the skeleton is cartilaginous, as well as the bony fish (*Osteichthyes*). Some consider, however, that only the bony fish should be classed as real fish.

Flood plain—The land bordering a stream built up of sediments from overflow of the stream and subject to inundation when the stream is at flood stage. Sometimes called bottomland.

Fringe wetland—Wetlands that parallel one or both sides of a *moving* body of water and occupy less than three times the width of the main channel on any line perpendicular to flow. Fringe wetlands on a *standing* body of water (e.g., lake or estuary) are those wetlands that cumulatively occupy less than one-third of the surface area of the standing body of water at the time of the highest annual water.

Function—See **Wetland function.**

Functional loss—The loss or decline of a valued wetland function as a result of wetland conversion or degradation.

Functional values—See **Wetland values.**

Goals and objectives—When designing and planning a replacement wetland, the goals and objectives are mainly calculating (1) the purpose of building the wetland, (2) the type of wetland to be created and the functions that are to be replaced, and (3) a sensible timeline for steps in the process.

Groundwater—Water that occurs below the Earth's surface contained in pore spaces within mantlerock and bedrock. It is either passing through or standing in the soil and underlying strata and is free to move under the influence of gravity.

Groundwater flow—The portion of total runoff that percolates through the ground, reaching the permanent water table and flowing underground to discharge eventually into a stream channel or other surface water body.

Growing season—The period and/or number of days between the last freeze in the spring and the first frost in the fall for the freeze threshold temperature of the crop or other designated temperature threshold.

Habitat—The environment occupied by individuals of a particular species, population, or community.

Heavy metals—These come from a variety of sources in a watershed, including surface-mined lands; point-source discharges; non-point sources, such as stormwater runoff; and from natural sources. In some areas of the country, background metal loadings may be of significant concern. There is considerable controversy about using replacement wetlands as retention areas for these constituents.

Herbaceous plants—Species that are not woody and that die back to the ground each year.

Hydric soil—A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation. Hydric soils that occur in areas having positive indicators of hydrophytic vegetation and wetland hydrology are wetland soils.

Hydrologic modeling—The use of small-scale physical models, mathematical analogs, and computer simulations to characterize the likely behavior of real hydrologic features and systems. Also called hydrologic simulation.

Hydrology—The science that relates to the occurrence, properties, and movement of water on the earth. It includes water found in the oceans, lakes, and rivers of the world, as well as in upland areas, above and below ground, and in the atmosphere.

Hydroperiod—A term that refers to the extent and duration of inundation and/or saturation of wetland systems. Stormwater wetlands tend to have a hydroperiod characterized by frequent to chronic inundation by standing water.

Impact—An action that adversely affects a wetland or other ecosystem (e.g., dam construction, timber clearing, or agricultural activities that result in wetland conversion or degradation).

Impermeable—A soil characteristic that prevents water or air from moving through it.

Indicator—One of the specific environmental attributes measured or quantified through field sampling, remote sensing, or, in some cases, compilation of existing data from maps or land use reports to assess ecosystem condition or functions or exposure to environmental stress agents.

Infiltration—As in soil infiltration, the gradual downward flow of water from the surface through soil to groundwater and water table reservoirs.

Infiltration rate—A soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water.

Inundation—A condition in which water from any source temporarily or permanently covers a land surface.

Invasive vegetation (Invading plant species)—Plant species that were absent in undisturbed portions of the original plant community and will invade under disturbance or continued overuse.

Isolated wetlands—Wetlands that are small (less than 10 acres) and have no connection to other surface water bodies. The term "isolated wetlands" is used in this document to refer specifically to those small, isolated wetlands that are covered under Nationwide Permit 26.

Lacustrine—A term used to describe wetlands and deep-water habitats formed from lakes with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, nonaquatic masses or lichens with greater than 30 percent areal coverage; and (3) greater than 20 acre (8 ha) in size.

Landfill (Sanitary landfill)—A method for the hygienic disposal of bulky wastes, in which the waste is deposited then covered with soil to prevent the contamination of adjacent land or water by leaching.

Landscape function—The combination of environmental processes operating within a landscape unit that account for the overall environmental characteristics of that unit. The term *wetland function* refers to the functions and benefits provided by individual wetlands, while *landscape function* refers to the functions and benefits provided by the landscape unit as a whole, including the complex of wetlands and other ecosystems within that landscape unit.

Low marsh—Periodically wet or continually flooded areas with the surface not deeply submerged. Covered dominantly with sedges, cattails, rushes, or other hydrophytic plants.

Maintenance—Defined as all work needed to keep the wetland replacement site in the condition designated in the original or modified construction plans.

Marsh—A more or less permanently wet area of mineral soil, as opposed to a peaty area (e.g. around the edges of a lake or on a flood plain of a river). Colloquially, marsh is often used interchangeably with swamp and bog although each is technically a different type of system.

Mean high water (MHW)—In a tidal system, the average height of the high water over 19 years.

Mean low water (MLW)—In a tidal system, the average height of the low water over 19 years.

Meander—The sinuous trace of a stream channel whose length is normally equal to or greater than 1.5 times the down-valley (or straight-line) distance. Over time, a meander may move laterally and/or vertically. Lateral movement, known as meander migration, involves the depositing of point bars on the inner sides of bends and erosion on the outer and is limited to a tract of flood plain called the meander belt.

Mineral soils—A soil consisting predominantly of and having its properties determined mainly by mineral matter. It usually contains 20 percent organic matter, but it may contain an organic surface layer up to 30 cm thick.
Minimum area—The minimum acreage required to satisfy the Target functional capacity units for each function being considered in the planned wetland. (Minimum area equals the Target functional capacity units divided by the Predicted functional capacity units).
Mitigation—See **Wetland mitigation.**
Mitigation banking—Wetland restoration, creation, or enhancement undertaken expressly for the purpose of providing compensation for wetland losses from future development activities. Banking includes only actual wetland restoration, creation, or enhancement occurring prior to elimination of another wetland as part of a credit program. Credits may then be withdrawn from the bank to compensate for an individual wetland destruction. Each bank will probably have its own credit system based upon the functional values of the wetlands unique to the area. As defined here, mitigation banking does not involve any exchange of money for permits.
Monitoring—The collection of information after construction to assess if the replacement project is successful and to keep the regulatory agencies and project sponsor staff informed about the status of the replacement project. Activities have involved both qualitative and quantitative evaluations to assess biological, physical, and hydrologic characteristics of the constructed replacement wetland.
National Wildlife Inventory (NWI) maps—These maps are produced by the United States Fish and Wildlife Service. They are produced at a scale of 1:24,000 and can be obtained as mylar overlays to USGS maps or as prints. These maps show wetland areas that are detectable from aerial photography. They are useful in identifying the location of existing wetlands.
Native (as in plants or species)—Applied to a species that occurs naturally in an area, and, therefore, one that has not been introduced by humans either accidentally or intentionally. Of plants found in a particular place, the term is applied to those species that occur naturally or are said to be indigenous to the region.
Natural buffer—A low sloping area of maintained grassy or woody vegetation located between a pollutant source and a waterbody. A natural buffer is formed when a designated portion of a developed piece of land is left unaltered from its natural state during development. A *natural* vegetative buffer differs from a *vegetated* filter strip in that it is "natural" and it does not need to be used solely for water quality purposes.
Nitrogen(N)—An element that is essential to all plant and animal life. It is found reduced and covalently bound in many organic compounds. Its chemical properties are especially important in the structures of proteins and nucleic acids.
Nitrification—The oxidation of ammonium, NH_4^+, to nitrite, NO_2^-, or nitrate, NO_3^-, by microorganisms.
Non-persistent vegetation—Emergent plants whose leaves and stems break down at the end of the growing season so that most aboveground portions of the plants are easily transported by currents, waves, or ice.
Non-point pollution—Impurities or contaminants derived from diffuse origins, such as farmland runoff, as opposed to pollutants that are introduced into a wetland or ecosystem at one or more point sources, such as from a wastewater treatment plant outlet.
Nuisance species—Species of plants that detract from or interfere with a mitigation project, such as most exotic species and those indigenous species whose populations proliferate to abnormal proportions. Nuisance species may require removal through maintenance programs.
Nutrients—Chemicals required for biological survival. Nitrogen and phosphorus are examples of plant nutrients.
Nutrient load—High concentrations of phosphorus and nitrogen (or other chemicals) that may result in algal blooms and the eutrophication of water bodies. These can degrade habitat and water quality with surface algal scums, odors, water discoloration, decreased oxygen levels, and toxin release.
Oil and grease (Pollutants)—Petroleum hydrocarbons are known to be toxic to aquatic organisms, even in small concentrations; however, in low levels and under the right conditions, they may not affect the replacement wetland.
Opportunity elements—Factors that consider the chance or opportunity that a wetland has to perform a function. For example, a wetland may possess the physical attributes required to perform floodflow alteration, but, unless the wetland is positioned in the watershed where it will receive floodflows, it will not have the opportunity to perform the floodflow alteration function.
Organic soils—Soils saturated with water for prolonged periods (unless artificially drained and having at least 12 or 18 percent organic carbon by weight, depending on the mineral fraction and the kind of organic materials) or soils never saturated with water for more than a few days and having 20 percent or more organic carbon by weight.
Osmotic pressure—The pressure that is needed to prevent the passage of water or another pure solvent through a semipermeable membrane separating the solvent from the solution. Osmotic pressure rises with an increase in concentration of the solution. Where two solutions of different substances or concentrations are separated by a semipermeable membrane, the solvent will move to equalize osmotic pressure within the system.
Palustrine—Meaning "marshy," it describes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such tidal wetlands where salinity from ocean-derived salts is below 0.5 percent.
Peat—An organic soil or deposit. Peat formation occurs when decomposition is slow owing to anaerobic conditions associated with waterlogging. Decomposition of cellulose and hemicellulose is particularly slow for *Sphagnum* plants, which are characteristic of such sites, and among the principal peat-forming plants.
Perched water table—A condition where the lake water is isolated from the groundwater table by impermeable material such as clay. Perched water tables are isolated from the permanent water table and are supported entirely by precipitation and resulting groundwater recharge.
Percolation —The downward movement of water through soil, especially through soil that is saturated or close to saturation. Percolation rate is the rate at which this water moves.
Permeability—The property of a membrane or other barrier determining the ease with which a substance will diffuse or pass across it. It relates the volume flow rate of water or a gas through a porous cross-section of soil, such as clay or coarse sand, as well as the rate at which plant roots can penetrate the soil.
Permeable—The quality of a soil layer that enables water or air to move through it. The permeability of a soil may be limited by the presence of one nearly impermeable layer even though the others are highly permeable.
Persistence—The overall ability of a wetland to continue to exist as a wetland and to serve wetland functions over a period of time

although its vegetation, soils, hydrologic characteristics, and precise boundaries may change.

Persistent emergents—Emergent wetland plants that typically remain standing at least until the beginning of the next growing season.

Persistent vegetation—Vegetation (woody or herbaceous) that normally remains standing at least until the beginning of the next growing season.

Phosphorous (P)—An element that is an essential nutrient for all living organisms. Plants require it in the oxidized form as orthophosphate (PO_4^{++}).

Physical alteration—A change in the physical structure or characteristics of a wetland or other ecosystem as a result of human activities (e.g., dredge and fill operations, planting, or timber harvesting).

Piezometer—An observation well designed to measure the elevation of the water table or hydraulic head of groundwater at a particular level. The well is normally quite narrow and allows groundwater to enter only at a particular depth, rather than throughout its entire length.

Point source pollution—Pollutants or toxins that can be traced to a specific source or inlet (e.g., an outlet pipe from a factory, a highway spill, or a leaking underground storage tank).

Pollutant—A by-product of human activities that enters a biological pathway or becomes concentrated to the extent that it may cause injury to living organisms or the functioning of environmental systems. In addition to chemical substances, the term also embraces noise, vibration, and alterations to the ambient temperature.

Pollution—The defilement of the natural environment by a pollutant.

Ponded—A condition in which water stands in a closed depression. Water may be naturally removed only by percolation, evaporation, and/or transpiration.

Porosity—The percentage of the total bulk volume of a body of rock or soil that is occupied by pore space. The figure may represent: (a) absolute porosity, which is the total of all pore spaces present in a rock or soil, not all of which will be interconnected and thus able to contain and transmit fluids; or (b) effective porosity, which is the proportion of the rock that consists of interconnected pores.

Prairie pothole—Small, palustrine marshes that are glacially derived and found scattered over the northern prairies from South Dakota and Minnesota through Manitoba, Saskatchewan, and Alberta. They are characterized by emergent plants interspersed with open water.

Precipitation—Generally, all the forms in which water falls to the ground (i.e., rain, sleet, snow, hail, drizzle, or other more specialized forms) and also the amounts measured. Sometimes precipitation seen falling from clouds evaporates before reaching the ground, but also it sometimes refers to airborne pollutants such as dust or industrial or agricultural releases.

Probability rating—A measure of the potential of a wetland to perform a function. A probability rating is not a direct estimate of magnitude of a function or a value, rather, it is an estimate of the probability that a function or value will exist or occur in a wetland to an unspecified degree.

Problem animals—Animals (both wild and domestic) that pose a threat to the replacement wetland project. These animals can include deer, rabbit, geese, carp, cattle, horses, and goats.

Process(es)—A natural phenomenon involving the biological, chemical, or physical conversion or transfer of some material. For example, nitrification and denitrification are processes within wetlands that contribute to the water quality function.

Pyritic soils—Soils containing metallic-looking sulfides of which iron disulfide, pyrite, FeS_2, is the most common.

Quality assurance/quality control (QA/QC)—Procedures that will be followed during a project to ensure continuous and overall productivity, successful completion, and presentation of a product/project. QA/QC is to be incorporated at all levels of a project from the planning stages through the wrap-up of a project. The five basic components of quality assurance are precision, accuracy, completeness, representativeness, and comparability.

Rapid assessment technique—Involves an integrated analysis of functional and structural components of the aquatic communities through use of metrics for benthic macroinvertebrates and fish.

Rare species—The relative abundance of a species and, therefore, its vulnerability to extinction. The rarity of a species is measured in terms of: (1) the extent of its geographic range; (2) the number of habitats it occupies at a single site (i.e., whether or not it is a specialist); and (3) whether it occurs in low numbers throughout its range or is common only in some areas. The International Union for Conservation of Nature and Natural Resources defines three categories of rarity. Species falling into any of these categories require special protection:

Endangered—the number of individuals has been reduced to a critical level or habitats so drastically reduced that if the causes of such reduction continue, there is an imminent risk of its extinction.

Vulnerable—a population that may become endangered in the near future, because most or all of its numbers are decreasing or have been depleted and their security cannot be guaranteed.

Rare—a species at risk because its population is small and usually confined to small geographic areas or habitats or scattered thinly over a larger area.

Recharge area—An area in which water is absorbed and added to the groundwater system.

Recharge rate—The speed at which water is absorbed and added to the groundwater system.

Reference wetland—An established wetland that is used as a comparative design guide to help determine the desired plant composition and species densities for the replacement wetland. It should be located near the replacement wetland site and have similar hydroperiod(s) and vegetation as that of the replacement site.

Relict—Applied to organisms that have survived while related ones have become extinct. Often the term refers to species that formerly had a much wider distribution and have survived locally through periods of unfavorable conditions (e.g., glacial periods or land submergence) by existing in some regions while becoming extinct elsewhere.

Replacement potential—The ability to recover a wetland and its valued functions through wetland restoration or creation.

Restoration—Restoration refers to the return to a pre-existing condition. It is not necessary to have complete knowledge of what those pre-existing conditions were; it is enough to know what type was there and plan to return to that same wetland type. Restoration also occurs if an altered wetland is further damaged and is then returned to its previous, though altered condition. That is, for restoration to occur it is not necessary that a system be returned to a pristine condition. It is, therefore, important to define the goals of a restoration project in order to measure the success properly.

Restored wetland—A wetland returned from a disturbed or altered condition to a previously existing natural or altered condition by some action of man.

Rhizomes—A horizontal underground stem usually rooting at the nodes and becoming erect at the apex.
Right of way—The legal right to use another person's property, as for a highway, railroad, or power transmission line. It is usually acquired by fair-value purchase.
Riparian systems—Ecosystems occurring at the interface of aquatic and terrestrial systems, in flood plains, rivers, and streams. Riparian systems are subject to direct influences of ground and/or surface waters (e.g., occasional flooding, root zones extending into the groundwater table). Riparian systems are valued for diverse functions such as flood reduction, groundwater supply, streambank stabilization, habitat and migration corridors for wildlife, erosion control, and preservation of water habitats.
Riprap—A combination of large stone, cobbles, and boulders used to line channels, stabilize banks, reduce runoff velocities, or filter out sediment.
Riverine wetland—Wetlands and deepwater habitats contained within a channel, not including wetlands dominated by trees or persistent emergents, or habitats containing more than 0.5 percent salt.
Runoff—That portion of the precipitation on a drainage area that is discharged from the area in stream channels. Types include surface runoff, groundwater runoff, or seepage.
Salinity—A measure of the total quantity of dissolved solids in water, in parts per thousand by weight, when all organic matter has been completely oxidized, all carbonate has been converted to oxide, and bromide and iodide have been converted to chloride. The salinity of ocean water ranges from 33 to 38 parts per thousand, with an average of 35 parts per thousand.
Salt marsh—Vegetation often found on mud banks formed at river mouths showing regular zonation reflecting the length of time different areas are inundated by tides. Sea water has a high salt content that produces problems of osmotic pressure for the vegetation so that only plants adapted to this environment (*halophytes*) can survive.
Saturated—A condition where the underlying soil is saturated to the surface for extended periods during the growing season, but surface water is seldom present.
Scrub/shrub wetland—The wetland class dominated by woody vegetation less than 6 m in height.
Section 404 permit—The permit issued by the Corps of Engineers under Section 404 of the Clean Water Act for authorizing the discharge of dredged or fill material into waters of the United States, including wetlands; also known as Corps permit, fill permit, Department of the Army permit, DA permit, individual permit, and 404 permit.
Sediment—Solid material, both mineral and organic, that is in suspension, being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level. Sediment loads could have a detrimental impact on a wetland replacement site. Sediments cause increased turbidity in water, which reduces light penetration and impacts aquatic life. Heavy sediment loadings can adversely impact planted vegetation in the initial years of the site by burying plants and altering substrates and grades. Many pollutants, such as nutrients and heavy metals, may be attached to sediments; therefore, sediments may be a contamination source as well.
Sedimentation—The process by which particulate material settles to the bottom of the water column of a wetland, lake, stream, or other water body.
Sediment accretion—The net accumulation of particulate material deposited within a wetland or other ecosystem.
Sediment loading—The quantity of solid material that is transported by a natural agent, such as a stream, and expressed as dry weight passing a given point in a given period of time.
Sediment stabilization—Wetlands function to stabilize and retain sediments previously deposited within the individual wetland.
Sediment trapping—The reduction in the quantity of particulate material carried by surface or groundwater as it passes through a wetland.
Seed—In the sexual reproduction of seed plants (*spermatophyta*), the seed is the discrete body from which a new plant develops. Formed from a fertilized ovule, the seed consists of an outer coat (which encases a food store) and an embryo plant. The term may also refer to a plant or animal structure propagation.
Seeding—A method of establishing vegetation by sowing seed artificially. In broadcast seeding, seed is sown over the entire area. Partial seeding may be done in strips, furrow rows, trenches, or in seed spots.
Shore configuration—The design or pattern of the vegetated and unvegetated substrate areas of the wetland located channelward of the bank.
Shoreline bank erosion control—Wetlands function to stabilize the shoreline bank and to dissipate erosive forces associated with waves, currents, ice, rainfall, seepage, obstacles in the water, water-level fluctuations, or groundwater flow. A shoreline bank is a steep ascending slope of land that can be undercut by water.
Shrub—A woody plant that branches below or near ground level into several main stems rather than from a central trunk. It may be deciduous or evergreen. At the end of each growing season, there is no die-back of the axes.
Site monitoring—See **monitoring.**
Slope—The degree of deviation of a surface from the horizontal. It is measured in a numerical ratio and expressed by percent or degrees of slope.
Soil—Unconsolidated mineral and organic material that supports plants and that has recognizable properties due to the integrated effect of climate and living matter acting upon parent material.
Soil amendment—Any material, such as lime, gypsum, sawdust, or synthetic conditioner, that is worked into the soil to make it help plant growth.
Soil Conservation Service (SCS) soil surveys—Produced by the United States Department of Agriculture. These maps are completed for most of the United States. Soil surveys identify major soil types, usually by county, and some of the associated slope characteristics. The soil types are generally drawn onto aerial photographs. In many parts of the country, hydric soils have also been drafted. Generally, soil surveys can be used to assess the soil types and characteristics of potential wetland replacement sites and to identify hydric soils in the watershed.
Soil seed bank—The ungerminated but viable seeds that lie in the soil.
Species—Literally, a group of organisms that resemble one another closely. The term derives from the Latin *speculare*, to look. In taxonomy it is applied to one or more groups (populations) of individuals that can interbreed within the group but cannot exchange genes with other groups (populations). Where barriers to gene flow arise such as a sea or areas of unfavorable habitat, this reproductive isolation may lead to distinct forms termed races or subspecies.
Specific yield—The ratio of the water drained from a rock under the influence of gravity, or removed by pumping, to the total volume of the rock voids or pore space in the drained rock. The difference is

caused by the retention of water in the rock, owing to molecular attraction and capillarity. Also, it describes the volume of water released by a falling water table from a given volume of a fully saturated rock.

Spring (Groundwater discharge)—A flow of water above ground level that occurs where the water table intercepts the ground surface. Where the flow from a spring is not distinct (i.e., it does not give rise to obvious trickles) but tends to be somewhat dispersed, the flow is more correctly termed a seep. The reappearance of surface water that has been diverted underground in a karst region is a type of spring known as a resurgence.

Stream gauge data—Also called stream elevation gauging. It is often necessary to determine where normal water levels are along a bank. In many states, only water above average base flow can be diverted from a stream and used. Gauging data determine what water levels are considered above this flow.

Stream monitoring—Used to determine the position of inlet structures to the wetland and their depth and design. Monitoring may be done by measuring stream elevations or stream velocity.

Stressor—Any material or process (physical, chemical, or biological) that can adversely affect a wetland and thus degrade wetland function.

Subsoil—The B horizons of soils with distinct profiles. In soils with weak profile development, the subsoil can be defined as the soil below the plowed soil (or its equivalent of surface soil), in which roots normally grow. Although a common term, it cannot be defined accurately. It is has been carried over from early days when "soil" was conceived as only the plowed soil and the earth under it as the "subsoil."

Success—Achieving established goals. Success in wetlands restoration, creation, and enhancement ideally requires that criteria, preferably measurable as quantitative values, be established prior to commencement of these activities. It is important to note that a project may not succeed in achieving its goals yet provide some other values deemed acceptable when evaluated.

Succession—The sequential change in vegetation and the animals associated with it. The colonization of a new physical environment by a series of vegetation communities until a final equilibrium state, the climax, is achieved.

Surface water runoff —The flow of water that accumulates on the surface when the rainfall rate exceeds the infiltration capacity of the soil. Surface runoff is determined by soil type, vegetation, and the presence of shallow, relatively impermeable, soil horizons. Saturated overland flow can occur when a temporary rise of the water table inhibits infiltration and causes flow over the surface.

Tide ranges—The difference in height between consecutive high and low waters. The tidal range varies from a maximum during spring tides to a minimum during neap tides. In tide tables, daily high- and low-water heights are given for each geographical locality mentioned.

Tolerance—The relative ability of a species to survive a deficiency of an essential growth requirement, such as moisture, light, or nutrient supply or an overabundance of a site factor such as water or toxic salts.

Topography—The configuration of a surface, including its relief and the position of its natural and man-made features.

TR 55 (Technical Release 55)—Technical Release 55 presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs.

Tree—A perennial plant having a permanent woody, self-supporting main stem or trunk.

Tuber—A thick, short, underground branch or part of a branch with many buds.

Turbidity—Optical property of water that causes light to be scattered or blocked by particulates in the water, resulting in decreased transparency.

Turion—A scaly, often succulent, shoot produced from an underground rootstock.

Uniqueness/heritage—The uniqueness/heritage function of a wetland addresses whether a wetland contains characteristics that render it important to humans for social or political reasons. Several elements used in this function describe special designations established by society to recognize the importance of preserving or protecting particular resources (e.g., Wild and Scenic Rivers, Natural Landmarks, Cultural Resources).

Upland (Upland site)—As used here, any area that does not qualify as a wetland because the associated hydrologic regime is not sufficiently wet for vegetation, soils, and/or hydrologic characteristics associated with wetlands. Such areas occurring within flood plains are more appropriately termed non-wetlands.

United States Geological Survey (USGS) Maps—These maps, which have scales from 1:24,000 to 1:2,000,000 and contour intervals of 10 to 150 feet, are useful in assessing the watershed area and determining its general topography. Recently updated versions can help determine general land-use patterns and possible access points to potential replacement sites.

USLE (Universal Soil Loss Equation)—An equation for predicting the average annual soil loss per unit area per year, $A = RKLSPC$, where R is the climatic erosivity factor (rainfall plus runoff), K is the soil erodibility factor, L is the length of the slope, S is the percent slope, P is the soil erosion practice factor, and C is the cropping and management factor.

Utilities—Public services in the form of sewers, waterlines, and power transmission lines that may be located on the replacement wetland site or where the companies that provide these services own easement rights to the proposed replacement site.

Vandalism—Unintentional or willful destruction or damage to the replacement wetland from sports, recreation, and vehicular intrusions. Plant materials and structures, such as check dams, weirs, and outlets are frequent targets.

Vegetation—The sum total of macrophytes that occupy a given area.

Vernal pool—As defined by Zedler, "a natural habitat of the Mediterranean climate region of the Pacific coast covered by shallow water for extended periods during the cool season but completely dry for most of the warm season drought." Plants must be able to endure both flooding and drought or be able to grow and reproduce during the short period of time that conditions are favorable. The pools can be seasonally or irregularly saturated or inundated.

Water quality—Wetlands function to influence water quality by various processes, including sedimentation, plant uptake and release, litter decomposition, soil nutrient retention, and microbial activity. The ability of a wetland to retain and process dissolved or particulate materials benefits the water downstream.

Water quality criteria—The U.S. Environmental Protection Agency-recommended levels for various water quality parameters.

Water quality standards—A law or regulation that consists of the beneficial designated use or uses for a waterbody, the water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.

Water rights—The legal right to the use of the water. They consist of riparian rights and those acquired by appropriation and prescription. *Riparian* rights are those rights to use and control water by virtue of ownership of the stream, lake, or ocean banks. *Appropriated* rights are those acquired by an individual to the exclusive use of water, based strictly on priority of appropriation and application of the water to beneficial use and without limitation of the place of use or to riparian land ownership. *Prescribed* rights are those to which legal title is acquired by long possession and use without protest of other parties.

Watershed—The upslope area from which surface waters (overland runoff and channel flow) enter the Assessment Area (AA)—the area for which functions and values are being assessed. The watershed for specific types of wetlands are defined as follows: (1) The watershed of tidal fringe wetlands (or nontidal fringe wetlands on lakes larger than 10 sq mi) begins at the outlet, or closest downstream constriction of the contiguous deepwater, and includes the area upslope of the AA from which water drains directly into the AA; and (2) the watershed of nontidal fringe wetlands begins at the outlet of the AA, or closest downstream constriction of the contiguous deepwater, and includes the areas upslope of the AA from which water drains directly into the AA, and, in addition, includes the areas upslope of contiguous areas of wetland or deepwater that flood the AA.

Water table—The upper surface of groundwater or the level below which the material is permanently saturated with water.

Watering requirements—The amount of water necessary to maintain moist soils throughout the root zones during the plant establishment period (i.e., the first growing season). Such watering often will be necessary for wetlands that are seasonally or temporarily flooded, particularly for regions of the country that experience drought periods during the growing season.

Wetland—Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Wetland evaluation models—Methods used by the Corps to assess the functions and values of wetlands.

Wetland function—As in wetland functions; the physical, chemical, and biological processes that can be attributed to a wetland ecosystem. Wetland functions are generally grouped into three categories: (1) habitat (providing the factors and conditions necessary to support wetland-dependent species); (2) water quality (improving the quality of "downstream" surface and groundwaters through the uptake of contaminants, sediment retention, nutrient retention, supply, and so forth); and (3) hydrology (moderating surface and groundwater flows, including flood attenuation, maintenance of base flow, and so forth).

Wetland mitigation—The President's Council on Environmental Quality defined the term "mitigation" in the National Environmental Policy Act regulations to include "(a) avoiding the impact altogether by not taking a certain action or parts of an action; (b) minimizing impacts by limiting the degree or magnitude of the action and its implementation; (c) rectifying the impact by repairing, rehabilitating, or restoring the affected environment; (d) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; and (e) compensating for the impact by replacing or providing substitute resources or environments" (40 CFR Part 1508.20 [a-e]). For the purposes of this document, mitigation refers only to restoration, creation, or enhancement of wetlands to compensate for permitted wetland losses.

Wetland mosaic—The complex or group of interconnected wetlands, often of different types and/or sizes, within a given geographic area.

Wetland Replacement Process (WRP) —An opportunity to provide a replacement wetland that provides those functions most needed at the wetland replacement site (i.e., out-of-kind replacement) rather than providing the same wetland type with the same functions as the wetland to be impacted (i.e., in-kind replacement).

Wetland restoration—Involves immediately returning habitat to its normal state after a temporary disturbance. This might include restoring grades and replanting vegetation disturbed during the installation of a utility line, removing temporary wetland fill used for access to construction or repair points, or replacing the original stream corridor after a stream diversion is no longer needed. The time frame for a restoration can be many years after the initial disturbance, but the goal of a restoration plan is to return the habitat to a more natural, less disturbed state. Wetland restoration generally involves three processes: physical, hydrological, and biological restoration.

Wetland type—A group of wetlands with common qualities and characteristics that distinguish them as an identifiable class. Several formal wetland classification schemes have been developed. The term wetland type is used here in a general sense and does not refer to any of these formal or standard wetland classifications. The wetland types discussed include freshwater emergent wetlands, bottomland hardwood forests, and wetlands within western riparian systems.

Wetland value—Wetland processes or attributes that are valuable or beneficial to society. Also, the goods and services that benefit human needs and that result from the functions performed by wetlands.

Wildlife—Any undomesticated organisms, although the term is sometimes restricted to wild animals, excluding plants.

Wildlife control structures—When wildlife grazing becomes a problem or a threat for the replacement wetland area, devices may be needed to stop this activity. Such devices would include fences and wildlife enclosures.

APPENDIX A
TYPE AND LOCATION OF WETLAND REPLACEMENT

A.1 INTRODUCTION

Appendix A provides an overview of the pros and cons of on-site, off-site, in-kind, and out-of-kind wetland mitigation from a wetland scientist's perspective. It also contains a brief discussion about wetland banking, a type of compensatory wetland mitigation. Appendix A is not intended to be an exhaustive treatment of the subject. However, it highlights important background information and technical considerations with which project sponsors should be familiar. Some of this material is presented in more detail elsewhere in this manual, although within a different context.

A.2 BACKGROUND

A.2.1 DEFINITIONS

The terms on-site, off-site, in-kind, and out-of-kind are widely used by wetland scientists and regulatory officials. Although they have not been formally defined from a legal perspective, they are used when establishing appropriate and practicable compensatory mitigation for unavoidable adverse impacts under the Clean Water Act Section 404(b)(1) Guidelines (U.S. EPA 1980; see *Memorandum of Agreement Between The Environmental Protection Agency and The Department of the Army Concerning the Determination of Mitigation Under the Clean Water Act Section 404(b)(1) Guidelines,* dated February 6, 1990; hereafter referred to as the Memorandum).

While the terms were used in the regulatory and technical literature prior to the issuance of this Memorandum (Army Corps of Engineers 33 CFR Parts 320-330, Office of Technology Assessment 1984, Pierce 1988, Kusler 1988), the U.S. EPA and Army Corps of Engineers explicitly used them in the Memorandum when spelling out the basic sequence of steps used by the federal government in determining compensatory mitigation requirements for all activities covered under the 404(b)(1) Guidelines, including those activities affecting jurisdictional wetlands.

Consequently, the terms have come to mean the following within the context of wetland replacement:

- **On-Site Wetland Replacement**: Mitigation of wetland losses by restoring or creating the replacement wetland adjacent to or contiguous to the location where unavoidable wetland impacts occur.
- **Off-Site Wetland Replacement**: Mitigation of wetland losses by restoring or creating replacement wetlands at some other location than adjacent to or contiguous to the location where unavoidable wetland impacts occur.

- **In-kind Wetland Replacement:** Mitigation of wetland losses by restoring or creating a replacement wetland which substantially replaces lost functions and values. In-kind wetland mitigation can occur either on-site or, to a lesser degree, off-site.

- **Out-of-kind Wetland Replacement:** Mitigation of wetland losses by restoring or creating a replacement wetland with different wetland functions and values from those provided by the lost wetland. Out-of-kind wetland mitigation may occur either on-site or off-site.

A.2.2 REGULATORY OVERVIEW

The United States Government has established a goal of no overall net loss of wetland values and functions. When wetland impacts cannot be avoided or minimized (pursuant to the sequencing requirements described in the joint Memorandum), then appropriate and practicable compensatory mitigation must be undertaken.

The U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency have established a policy that such compensatory actions should be undertaken "when practicable, in areas adjacent or contiguous to the discharge site" or on-site. If on-site wetland mitigation is not practicable or environmentally feasible, then mitigation must be undertaken off-site in the same watershed. If compensatory mitigation is determined not to be practicable within the same watershed, generally the regulatory agency will look to adjacent watersheds until it identifies a suitable replacement site. Finding a replacement site at a location other than one adjacent or contiguous to the impact site is generally referred to as off-site wetland mitigation.

In establishing the specific mitigation requirements and methods, the lost functions and values must be considered. The Corps and U.S. EPA have established preference for in-kind mitigation, i.e., replacement of the same wetland functions and values as those lost by the impacted resource. Out-of-kind wetland mitigation providing different wetland functions and values than those lost is possible only if there is not a likelihood of success in constructing the replacement wetland and/or project staff determine that it is not practicable to provide the same functions and values.

Some regulatory officials have come to view functional replacement as replacing the impacted wetland with the same wetland type, i.e., a scrub/shrub wetland is replaced by another scrub/shrub wetland or a freshwater emergent wetland is replaced with another freshwater emergent wetland. This perspective, however, which is habitat-based only, ignores other wetland functions and values such as sediment/toxicant retention, sediment/erosion retention, floodflow alternation, etc., and therefore oversimplifies the mitigation process. The same wetland type in different locations may provide very dissimilar wetland functions and values depending on the hydrogeomorphic setting, the hydrodynamics, and water source and transport characteristics. Consequently, from a scientific perspective, it is essential to assess the specific functions provided by the impacted wetland to the maximum extent possible using currently accepted evaluation methods (Chapter 2).

When considering the wetland mitigation method, most wetland scientists generally consider restoration the preferred method or approach due to its higher likelihood of success (Kusler and Kentula 1990). If restoration cannot be accomplished, then wetland creation should be considered as the next most desirable alternative. Wetland enhancement is the least preferred option because, generally, this approach only results in enhancement of existing functions and values and does not replace lost functions and values. Enhancement also often results in degradation of other functions (Kruczynski 1990). A more complete discussion on wetland restoration and enhancement is provided in Appendix C.

Finally, wetland mitigation banking is a particular type of compensatory wetland mitigation. A wetland bank is usually constructed off-site, although on-site banks have been approved. Banks may comprise both in-kind and out-of-kind wetland mitigation.

A.3 WETLAND CHARACTERISTICS

Wetlands are highly diverse and complex ecosystems. They vary widely in size, species composition, species diversity, hydrology, geology, and subsequent types of wetland functions and values provided. More importantly, they are dynamic ecosystems potentially subject to ongoing change (Niering 1994). In some cases, they can be very stable over time, although man-induced and natural cyclical and noncyclical disturbances can quickly alter wetland characteristics to cause rapid change in the wetland itself and potentially the functions and values it provides.

Because wetlands represent a continuum between terrestrial and aquatic ecosystems, they encompass properties of each while also having unique properties unto themselves (Mitsch and Gosselink 1993). Since they are very much interdependent with and connected to adjacent terrestrial and aquatic ecosystems, changes to these systems will most likely affect the wetland. This complexity—dynamic characteristics (seasonal, temporal, etc.) and the linkage to terrestrial and aquatic systems—presents difficult questions regarding wetland mitigation design. Clearly, from a purely ecological perspective, while in-kind replacement may result in successful replacement of lost functions and values, a closer look at the components of the wetland systems (biomass, nutrient cycling, vegetation composition etc.) within 3 to 5 years or longer after construction will likely reveal subtle and often not-so-subtle differences between the replacement wetland and the original wetland site or reference site. Studies have been completed which document the differences, e.g., Craft et al. 1991, Streever and Crisman 1993, Webb and Newling 1983, LaSalle et al. 1991, Zedler and Langis 1991, Craft et al. 1989, Confer and Niering 1992. These findings of differences are not surprising given that wetland ecosystems and the component parts have evolved over a considerable time, while the constructed wetland has existed only for a short time.

In fact, certain wetland ecosystems or types are easier to replicate. For example, a freshwater emergent marsh replication might reach maturity in 2 to 5 years, whereas a mature bottomland hardwood forest might take up to 100 years to develop. Some wetlands types have been found to be extremely difficult, if not impossible, to replace. Some of the known reasons include the following:

- Plant species in the wetland have unknown biology, life history, and ecological characteristics.
- The wetland hydrology is complex and, therefore, difficult to replicate.
- The substrate requirements are unknown or too complex to establish.
- The system relationships of the wetland are unknown and, therefore, it is difficult or impossible to replicate functions provided by the wetland.

The following sections examine the technical and scientific considerations briefly discussed above with respect to on-site/off-site and/or in-kind/out-of-kind wetland replacement.

A.4 ON-SITE VERSUS OFF-SITE MITIGATION

From a theoretical and practical perspective, on-site mitigation can offer several important advantages while entailing disadvantages which ultimately can impact whether the replacement project will be successful over time. Important advantages, depending upon the replacement type, include:

- The hydrology is already established.
- Existing vegetation may serve as a seed source for revegetation of the replacement wetland.
- The site is already under protective ownership.
- The existing and future land use adjacent to the mitigation site will not degrade surface runoff and groundwater water quality.
- The lost functions are more likely to be replaced (assuming in-kind mitigation is the goal) within the same landscape position than within a new one and, therefore, the lost functions and values are more likely to return.

Important disadvantages include the following:

- Development may degrade stormwater runoff water quality into the wetland due to the introduction of nutrients and other potential chemical pollutants.
- Baseflow and excess surface runoff quantities from adjacent areas may be sufficiently modified to cause a change in the site's hydrology. This may, in turn, alter the vegetation type depending upon changes in the frequency and duration of inundation/saturation within the replacement site.
- The site becomes isolated due to the proposed adjacent development, thereby reducing its overall value within the watershed and its attractiveness to wildlife.
- Increased vandalism is possible due to adjacent development.
- The existing site hydrology may be degraded by future development or the permitted activity itself and thus the future site hydrology may not be sufficient to fulfill the required wetland replacement ratio.
- Maintaining functions of remnant wetlands and the replacement of lost functions and wetlands on site may be incompatible with future development.
- A loss of wetland functions and values may occur until the replacement wetland has been constructed and had sufficient time to achieve the replacement goals and objectives.
- On-site mitigation may be more expensive overall due to site conditions than at an off-site location.

Off-site mitigation may be in some cases more practical and have a higher likelihood of success due to fewer environmental problems than those found on-site. Specifically, constructing the wetland replacement off-site may provide the following advantages:

- Greater opportunity to select a site which may be protected from future development, thus controlling or minimizing long term water quality and quantity impacts.
- Greater opportunity to select a site at which more reliable hydrology may already exist or be established to support the replacement wetland goals and objectives.
- The costs may be lower to construct the replacement site due to lower earth moving and site preparation costs.

- A knowledgeable site manager is willing to take responsibility for site monitoring and long-term maintenance.

- The off-site replacement may advance the goals of the comprehensive wetland plans developed to protect and promote wetland conservation within a specific watershed.

There may be many other advantages and disadvantages—which are not covered here—to consider when comparing on-site versus off-site mitigation on a regional basis. Also, the above advantages and disadvantages could shift categories depending on the specific site conditions. For example, different land use types adjacent to the site may degrade or enhance surface or ground water. Site conditions off-site may be such that buffers in the broadest sense can be incorporated into the design while they cannot be at on-site locations. Finally, an off-site watershed hydrology may be such that it may likely remain over time versus an on-site location that may be threatened due to planned development.

A.5 IN-KIND VERSUS OUT-OF-KIND MITIGATION

In-kind mitigation involving the replacement of lost wetland functions and values is given first priority from a regulatory perspective, although practically, the ability to restore or create particular wetland functions varies (Kusler and Kentula 1990). The success of replacing lost functions will be influenced by a variety of factors (Kusler and Kentula 1990, Brinson 1993). They include:

- What fundamental knowledge exists about the wetland function

- The ability to design and construct structural characteristics known to support specific functions

- The availability of a suitable site

- The availability of a suitable hydrology

For example, knowledge about providing waterfowl habitat for breeding and feeding is well known, as is restoring and creating flood storage and flood conveyance functions. Creating suitable habitat for other species, particularly threatened and endangered species, will be a much more complex task than establishing the breeding/feeding and flood storage/conveyance functions due to the probable need to recreate specific food chain functions on which these species may depend. Creating groundwater recharge and discharge functions also can be more difficult than habitat functions.

From a practical perspective, if unavoidable wetland impacts result in lost functions which are difficult to replicate, out-of-kind wetland replacement will be more practicable and effective.

When determining if in-kind or out-of-kind compensation will be the mitigation goal, a critical factor to consider is whether experience shows that in-kind replacement is possible. While the lack of documented success should not preclude attempts, project sponsors must be prepared to accept that greater effort might be required to design and construct a successful wetland replacement with a goal of in-kind replacement. Conversely, there might be a higher likelihood of failure. Unless they can demonstrate otherwise, project sponsors must be prepared to conduct ongoing monitoring and maintenance to ensure that mitigation goals and objectives are met.

The selection of out-of-kind compensation as the mitigation goal depends on wetland type affected, local and state wetland mitigation policies, and the experience of the wetland replacement design team.

A.6 WETLAND MITIGATION BANKS

A.6.1 OVERVIEW

Wetland banks are formally defined as sites where wetlands have been restored, created, enhanced or, in rare cases, preserved expressly for the purpose of providing compensatory mitigation in advance of authorized impacts to similar habitats. Banks can be created both on-site and off-site (e.g., adjacent to the project site, either on suitable excess land already owned by the project sponsor, adjacent land requiring acquisition, or at a remote site).

Banks are generally established under two broad scenarios. In the first scenario, the project sponsor creates larger or excess wetland acreage above the amount actually required to be mitigated. The extra acreage amounts can then be "credited" toward future authorized discharges by the project sponsor (client created credits), provided the sequencing requirements have been met. Under the second scenario, a "bank manager"—typically a private or public entity or a public/private partnership—creates the wetland bank independent of a specific project and then sells credits to project sponsor(s) who are required to mitigate authorized fills and who, after having gone through the sequencing requirements, cannot locate suitable wetland mitigation sites near the project area. This second scenario, in its most sophisticated form has been referred to as the "credit market system" (Shabman et al. 1993).

While wetland banks differ widely in their structure, they generally include six essential functional components according to the Environmental Law Institute (ELI 1993):

- **Client**: The entity or entities whose activities will create a wetland impact for which mitigation is being sought through the bank.
- **Permitting**: The process whereby regulatory officials determine that a project with unavoidable wetland impacts will be allowed to proceed; if allowed, officials then decide what mitigation requirements should compensate for unavoidable adverse wetland impacts. Generally wetland banking has not been allowed unless sequencing requirements (avoidance, minimizing) have been satisfied, although this has not always been the case. Only then can the sponsor begin to explore banking. Usually during this stage, the sponsor(s) will also establish an agreement signed by the various interested parties detailing the terms and conditions of the wetland bank.
- **Credit Production**: The actual process of producing the credits by constructing successful wetlands via restoration, creation, etc. Monitoring and maintenance elements are also included within this function to ensure successful wetland mitigation.
- **Long-term property ownership**: The creation of enforceable legal mechanisms via transfer of property rights, formal contract, or other mechanism to an entity that will be responsible for long-term property ownership.
- **Credit Evaluation**: The process of defining and establishing the value of credits and the type of "currency" is an essential function to consider when establishing a bank. Usually currency is measured in acres, habitat-based units, or multiple-function-unit-based systems (ELI 1993). Credit evaluation requires an approach for valuing the compensation credits produced and for determining the type and number of credits required as compensation for authorized project discharges to wetlands. Defined credits establish a basis for measuring replacement under the terms of the permit (replacement ratio). Credit definition and evaluation can be extremely complex and involved.
- **Bank Management**: This function involves establishing a management entity and structure to ensure that the terms and conditions agreed on when the bank was established are met. The

management function may be undertaken by the project sponsor, by a regulatory or resource agency, or by a third party.

Many different combinations of the above six components are possible (ELI 1993). Usually state Departments of Transportation (DOTs) use a single-client approach where the DOT (client) is also the credit producer, while credit evaluation and bank management may be performed by a regulatory agency(ies), i.e., a permit agency or other govemmental entity. Some DOTs have been successful in establishing a resource agency bank. In this case, the credit production function is shifted from the DOT to a state, local, or quasi-public resource agency with technical experience in constructing and managing wetlands. Under this arrangement, the DOT is only responsible for providing the financial resources to ensure the bank is successful.

Any entity attempting to establish a bank should be aware that considerable time and effort may be required to seek approval for the bank. Usually time is expended in securing agreement between the various stake-holders on the bank's structure. Generally these stake-holders may include the state DOT; Federal Highway Administration; Army Corps of Engineers; U.S. Environmental Protection Agency; state resource agencies, such as Departments of Natural Resources; state regulatory agencies; and local entities. In addition, locating a suitable site for a bank may require considerable upfront effort to screen possible locations and to complete the evaluations necessary to confirm the suitability of the site and to verify the likelihood of success for the mitigation design.

The initial costs of establishing banks are often substantial due to the larger acreage involved and the increased scope of the project although use of suitable excess lands (previously purchased right of way) can reduce the cost. The cost of total wetland credits in banks is often less than that for project-by-project (on- or off-site) mitigation.

A.6.2 WETLAND MITIGATION BANK ADVANTAGES AND DISADVANTAGES

Wetland mitigation banks offer several important advantages provided the bank is consistent with the accepted wetland replacement goals and objectives:

- They minimize a piecemeal approach to wetland mitigation by constructing a wetland(s) at a single site rather than constructing many smaller wetlands at several isolated sites.
- Banks save time over on-site mitigation due to construction of the bank in advance of the permitted discharge and the loss of wetland functions and values.
- Larger wetlands provide ecological advantages for wildlife due to increased habitat size provided this out-of-kind wetland replacement goal is acceptable to regulatory agencies.
- Banks speed up the permit process by providing readily available wetland bank credits instead of requiring the project sponsor to conduct a search for a suitable wetland mitigation site and to pay for the studies required. (Note: sequencing still needs to be considered in most cases before a bank may be used, e.g., on-site or off-site.)
- Potentially, banks reduce on-site wetland mitigation construction, monitoring, and maintenance costs.

Most of the disadvantages which have been reported for wetland mitigation banks are due to technical failures associated with constructing the replacement wetland (failure to achieve replacement goals and objectives), effectiveness of the bank's management over time, and the governmental polices toward the use of banks. The likelihood that off-site mitigation will not result in functional replacement due to the site location in a different portion of the watershed or in a different watershed is also frequently cited as an important disadvantage. However, this disadvantage has more to do with the problems of off-site wetland mitigation generally, rather than with the concept of wetland banking itself.

Probably the greatest concern expressed to date is that banking can reduce incentives to avoid and minimize wetland discharges because it provides a ready source of credits. However, this concern can and should be addressed as a regulatory issue by officials charged with overall wetland protection when they review individual banking projects.

A more detailed treatment of the subject of wetland banking may be found in Environmental Law Institute (1993).

A.8 REFERENCES CITED

Confer, S.R. and W.R. Niering. 1992. Comparison of Created and Natural Freshwater Emergent Wetlands in Connecticut (USA). Wetlands Ecology and Management 2(3): 143-156.

Craft, C.B., W.S. Broome, and E.D. Seneca. 1989. Exchange of nitrogen, phosophorous, and organic carbon between transplanted marshes and estuarine waters. Journal of Environmental Quality. 18(2):206-211.

Craft, C.G., E.D. Seneca, and S.W. Broome. 1991. Porewater chemistry of natural and created marsh soils. J. Exp. Mar. Biol. Ecol. 152:187-200.

Brinson, M.M. 1993. A Hydrogeomorphic Classification for Wetlands. Wetland Research Program Technical Report WRP-DE-4. US Army Corps of Engineers, Waters Experiment Station. Vicksburg, MS. 79 pp. plus appendix.

Environmental Law Institute. 1993. Wetland Mitigation Banking. Environmental Law Institute, Washington, D.C. 159 pp. plus appendices.

Kruczynski, W.L. 1990. Options to Be Considered in Preparation and Evaluation of Mitigation Plans in Wetland Creation and Restoration. The Status of the Science. Ed. Kusler, J.A., and M.E. Kentula. Island Press. Washington, D.C. 594 pp.

Kusler, J.A. 1988. Wetland Restoration/Creation: A Summary of Science Views and Perspectives. In Proceedings of the National Wetland Symposium: Mitigation of Impacts and Losses. ASWM Technical Report. Held October 8-10, 1986 New Orleans, Louisiana. pp. 287-289.

Kusler, J.A. and M.E. Kentula. 1990. Wetland Creation and Restoration, the Status of the Science. Island Press. Washington. D.C. 594 pp.

LaSalle, M.W., M.C. Landin, and J.G. Sims. 1991. Evaluation of the flora and fauna of *Spartina alterniflora* marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2):191-208.

Niering, W. 1994. Wetland vegetation change: a dynamic process. Wetland Journal 6(4):6-10.

Mitsch, W.J. and J.G. Gosselink. 1993. Wetlands. 2nd Edition. Van Nostrand Reinhold, New York.

Office of Technology Assessment. 1984. Wetlands: Their Use and Regulation. OTA-O-206. U.S. Congress, Washington, D.C.

Pierce, Gary J. 1988. In-Kind vs. Out-of-Kind Wetland Replacement. In Proceedings of the National Wetland Symposium: Mitigation of Impacts and Losses. ASWM Technical Report. Held October 8-10, 1986 New Orleans, Louisiana. pp. 287-289.

Shabman, L., D. King, and P.F. Scodari. 1993. Wetland mitigation success through credit market systems. Wetland Journal 5(2):9-12.

Streever, W.J. and T.L. Crisman. 1993. A preliminary comparison of meiobenthic claoceran assemblages in natural and constructed wetlands in central Florida. Wetlands 13(4):229-236.

U.S. Environmental Protection Agency. 1980. Section 404(b)(1) Guidelines for Specification of Disposal Sites for Dredged or Fill Material (40 CFR 230.1-230.80). Federal Register 45:85344.

Webb, J.W. and C.J. Newling. 1975. Comparison of natural and man-made salt marshes in Galveston Bay Complex, Texas. Wetland 4:75-83.

Zedler, J.B. and R. Langis. 1991. Comparisons of constructed and natural salt marshes of San Diego Bay. Restoration and Management Notes 9(1):21-25.

APPENDIX B
REGULATORY PLANNING PROCESS FOR WETLAND REPLACEMENT

B.1 INTRODUCTION

The regulatory planning process is an important step in wetland replacement projects. It requires communication with federal, state, and local regulatory agencies on a regular basis to keep them fully informed about the project's progress. The design and construction of the wetland replacement is often a key permit condition. Therefore, it is an issue that the regulatory agencies often monitor closely. The permit conditions for the wetland replacement usually are established prior to issuance of the permit (the permit application process is not covered in the *Guidelines*).

As a matter of practice, some review agencies submit comments on the wetland replacement project to the lead agency and, by law, the lead agency must consider those comments in its permit decision. However, the review agencies' comments are not binding. Governed by state regulations, this review process varies from state to state and, therefore, cannot be fully addressed in this appendix. The federal process is generally outlined below, but it, too, will vary from state to state because of the states' differing procedures.

The federal permit process, and thus the wetland replacement process as it applies to the permit conditions, is generally administered by the U.S. Army Corps of Engineers (ACOE). Much of this jurisdiction is through the Clean Water Act, administered by the United States Environmental Protection Agency (U.S. EPA). The United States Fish and Wildlife Service (U.S. FWS) and the National Marine Fisheries Service (NMFS) provide technical comment on permit applications. Comments provided by the U.S. FWS and NMFS must be considered by the ACOE in the permit decision process, but their comments are not binding. Unlike the other review agencies, the U.S. EPA has the authority to veto any ACOE permit decision.

In addition, most state resources agencies are given the opportunity to comment on the plan. More importantly, separate Section 401 water quality certification may be required from the state agency responsible for maintaining water quality before an individual Corps permit, and some nationwide permits, are issued. Some states will not issue the 401 certification until an acceptable wetland mitigation plan has been submitted and approved. If 401 water quality certification is denied, then the Corps will not grant a Section 404 permit. States that have taken over the Section 404 program will have the lead over the federal agencies in issuing permits.

B.2 ELEMENTS IN THE REGULATORY PLANNING PROCESS

B.2.1 PERMIT CONDITIONS AND COMMUNICATIONS ABOUT THEM

The permit conditions should dictate the size and type of wetland replacement. Time lines for completion of the various tasks in the wetland replacement process (i.e., conceptual plan, final plans and specifications, and construction) and monitoring requirements are often part of the permit requirements. Additionally, some permit conditions may include periods when construction is prohibited because of potential disturbance to fisheries resources or endangered species use (Chapter 2).

During the entire project, it is appropriate to discuss by telephone any project-specific issues with the respective agency project managers to give them informal project updates. Any conversation where a decision is made to alter a condition of the permit, regardless of how trivial it may seem, should be followed up with a letter documenting the conversation. Documentation is particularly important because agency personnel turnover is common. Clear documentation in writing about what has transpired will help avoid confusion and ease the transition to a new project manager.

It also may be helpful to meet with the interagency review team prior to the wetland replacement site selection to receive initial agency comment on the project. Agency input about expectations for the project, including recommended design elements, can be very helpful and could ultimately expedite the approval process.

B.2.2 SITE SELECTION

During the site selection process (Chapter 2), telephone calls should be made to the project manager from the lead permit agency every six to eight weeks to provide a project update and to inform him or her of any problems that may arise or of any deadlines that may be missed due to unforeseen circumstances. It may be appropriate to submit site-specific data to the agencies for their review as it is collected and analyzed. However, before submitting these data, verify that the agencies wish to receive the information. Then, review of the data by the agencies may expedite the final approval of the final design and specifications. As with all regulatory decisions pertaining to the project, any time extensions or other project changes agreed to on the telephone should be followed up in writing.

B.2.3 CONCEPTUAL PLAN

After the replacement site has been selected (Chapter 2) and the conceptual mitigation plan completed (Chapter 3), the conceptual plan will be submitted to the lead agency for distribution and interagency review. Depending on agency work loads, it may be several weeks before their responses are received. A follow-up telephone call to the lead agency should be made to ensure that the plan has been received and to learn if there are any questions about it.

The lead agency will generally request a visit to the proposed wetland replacement site prior to issuing a comment letter. After the site visit, the lead agency will formally request comments from all of the review agencies. The lead agency will then provide a cover letter to the project sponsor with its comments and copies of the other agencies' review letters. This process may also take several weeks. It is appropriate to call the lead agency project manager two to three weeks after the site visit for an update on the progress of the review.

Agency review letters sometimes contain conflicting comments. Items such as whether open channels or culverts are more appropriate, where open water should be placed on the site, or what plant species are preferred in the planting plan often appear in the comment letters. In extreme cases, the appropriateness of the proposed replacement site may even be an issue to some agencies.

In instances of conflicting comments, it is important to consider the comments and try to reach compromises. Doing so may entail another interagency meeting to discuss the issues. It is important to explain to the agencies why the chosen conceptual design is the best alternative. If the comments from the agencies provide better alternatives, their recommendations should be incorporated into the final plan as long as the modifications are feasible for the site and cost-effective.

In an impasse it is important to satisfy the comments of those agencies with control over the project. Discuss the impasse with the project manager from the lead agency to learn what agencies at the state and federal levels must be satisfied in order to meet the permit conditions. Under some circumstances commenting agencies may be very unhappy with the final decision for the replacement wetland design and its location. However, as long as their comments were considered, the final decision lies with those agencies at the state and federal levels that issue the permit.

Comments may call for additional information, such as hydrologic monitoring (i.e., stream gauges or groundwater wells; Chapter 4), endangered or threatened species surveys, and/or subsurface soil investigations. As with conceptual design considerations, the comments must be considered and a reply made. It should outline why the additional study is not necessary or how the information in the request will be provided. After any issues about the conceptual plan have been resolved, the lead agency will send a written response approving the site and the conceptual plan.

B.2.4 FINAL PLANS AND SPECIFICATIONS

Before completing the final plans and specifications, it is recommended that the design be presented at another interagency meeting. At this meeting, agencies will make final comments. As in the conceptual plan, the comments should be incorporated into the design whenever appropriate. In instances where conflicting comments arise, rely on the advice of the lead permit agency.

Once plans and specifications are complete, they will be submitted to the lead agency for distribution and agency review. Comments will generally be minor if the wetland design team has been working closely with the agencies. They may refer to specifications, such as fertilizer type, soil amendments, or plant species that were chosen. These comments are generally easy to address.

B.2.5 CONSTRUCTION

During construction, agency representatives may request a site inspection; often they will ask to be briefed on the construction sequence and process. Progress reports may also be required, especially if the wetland replacement construction is done in phases.

B.2.6 MONITORING

Most permits require monitoring of the replacement wetland for a specified period of time, which generally is from three to five growing seasons. Unless problems arise on the site (e.g., loss of vegetation, blockage of waterflow, and vandalism) that require corrective action, the monitoring will entail only:

- One to two site visits per year during the monitoring period
- The preparation of a short findings report
- Representative photographs with captions

B.2.7 ULTIMATE OWNERSHIP OF THE WETLAND REPLACEMENT SITE

It is very common that one of the permit conditions will require a permanent conservation easement or similar restriction on the wetland replacement site. Therefore, it is important that a decision about ultimate ownership of the site and maintenance responsibilities be made. Frequently, a replacement wetland can be deeded to a state or federal land management agency (e.g., fish and wildlife, parks, and forestry), especially if the property is large or adjacent to an existing holding. Deeding the site over to a land management agency has several advantages, including the guarantee that the site will be protected. It also relieves the permit holder of long-term maintenance requirements.

B.2.8 PROBLEMS AND THEIR SOLUTIONS

Most regulatory problems that arise in the wetland replacement process involve meeting the deadlines dictated in the permit(s). In extreme cases, it may be difficult to find a site to meet the acreage required and/or support the type of wetland specified in the permit. In wetland replacement projects, such delays are common. If the replacement wetland design team works closely with the agencies and shows a good faith effort, then serious permit problems rarely arise.

Unforeseen problems in the wetland replacement process can occur, however. Some of the most common are listed below.

- **Inability to find a suitable location for the wetland replacement.** In this situation, the acreage of the specified wetland type may have to be reduced and the additional acreage made up by creating a different wetland type. Possibly the specified wetland type will have to be changed, or the project will have to be moved to a different watershed. These instances require a modification of the permit conditions.

- **During acquisition of the site, problems—including litigation—may arise that will require a time extension on the permit conditions.**

- **Delays in acquiring other needed permits, such as for sediment and erosion control or for water diversion or usage** (particularly in the west and southwest), may also delay the project.

In all of the above circumstances, it is important to notify the lead agency in writing about expected delays and other potential changes to the permit conditions. Project sponsors should request that the agency provide, in writing, its approvals for time extensions or other permit modifications.

B.3 NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) AND WETLAND MITIGATION

NEPA requires the preparation of an environmental impact statement (EIS) for all federal actions that significantly affect the quality of the human environment (receipt of federal funds and permit issuance constitute federal actions). The Council on Environmental Quality has adopted regulations governing the NEPA process that are binding on all federal agencies, including the Army Corps of Engineers and the Federal Highway Administration.

Generally, project sponsors involved in wetland mitigation may coordinate with NEPA in two ways. First, if the entity receives funds from the Federal Highway Administration (FHWA), that agency has an established policy requiring state departments of transportation and state highway agencies to integrate the Section 404 procedures into the NEPA process. Consequently, if a project impacts wetlands and mitigation is required, it may be necessary to complete portions of the Section 404 process before receiving a sign off on NEPA documents—usually an environmental assessment (EA) or an EIS. Depending on the state and the Corps District, requirements can range from (1) establishing that there are no feasible avoidance alternatives to impacting wetlands and then making commitments that mitigation will take place prior to construction to (2) locating the wetland replacement site, assessing the impacts of constructing the wetland on the site, and obtaining approval of a conceptual plan before NEPA documents can be approved.

The second way involves most private sector permit applicants. In these cases, federal funds are not involved but an agency decision constitutes the federal action—i.e., the Corps of Engineers issuing a permit. In this situation, the Corps may require the permit applicant to submit the information necessary to prepare an EA or an EIS for the project. It may also solicit and respond to public comments on the draft environmental assessment or environmental impact statement. For major or controversial projects involving Section 404, an applicant may be required to prepare the EA or EIS and submit it with other permit documents (i.e., wetland mitigation plans) before the Corps will issue a Section 404 permit.

APPENDIX C
WETLAND RESTORATION AND WETLAND ENHANCEMENT

C.1 INTRODUCTION AND DEFINITIONS

The terms "restoration" and "enhancement" are frequently used interchangeably in the literature. In addition, the Society of Ecological Restoration (SER) has developed a definition of "restoration" that encompasses most aspects of mitigation, including replacement (creation), restoration, and enhancement. For the purposes of this manual, the definitions of restoration and enhancement will follow the most straightforward use, the dictionary definition, similar to that developed by Lewis (1989) and Kruczynski (1989):

- **Restoration:** "a reconstruction or representation of an original form" (Mish 1989). Wetland restoration, for the purposes of this manual, is changing an altered wetland from its present, impacted condition into a less impacted, functioning wetland.

- **Enhancement:** "to make greater as in value or desirability" (Mish 1989). Wetland enhancement generally is a process by which certain wetland functions are improved as part of an overall management scheme.

C.2 WETLAND RESTORATION

Wetland restoration, in its simplest sense, involves immediately returning habitat to its normal state after a temporary disturbance, e.g., by restoring grades and replanting vegetation disturbed during the installation of a utility line; removing temporary wetland fill used for access to construction or repair points; or replacing the original stream corridor after a stream diversion is no longer needed. The time frame for a restoration can be many years after the initial disturbance, but the goal of a restoration plan is to return the habitat to a more natural, less disturbed state. To do so, wetland restoration generally involves three processes: physical, hydrologic, and biological restoration. A successful project can include only one or a combination of these processes.

Restoration, like enhancement, can be a successful part of an overall mitigation plan. Physical restoration of a filled wetland site can be accompanied by site enhancement with additional water channels or ponds. Restoration of wetlands can also be used with the construction of new wetlands to provide the project with additional environmental benefit.

C.2.1 REGULATORY CONSIDERATIONS

Wetland restoration can often be considered as mitigation in lieu of creating wetlands, especially if the disturbance is an old one occurring before regulatory jurisdiction took effect. Historically buried wetlands and those that have been diked or drained make likely candidates.

From a regulatory perspective, restoration is often desirable because the disturbed site was historically wetland. This gives some assurance that the site can function as one again. Depending on the severity of the disturbance, a restoration may be permitted on a 1:1 acreage basis, particularly if the site disturbance consists of old fill.

Although restoration is considered desirable, care should be exercised in making the site selection: sites with fill violations associated with them could prove to be problematic because regulatory violations are generally resolved by restoring the site: resolving a fill violation and satisfying a mitigation requirement with the same restoration project is usually considered inappropriate from a regulatory perspective.

C.2.2 WETLAND RESTORATION CASE STUDIES

C.2.2.1 Physical Restoration

Physical restoration generally implies removing fill from a site to restore wetland function. LaPerriere and Farmer (1988) discuss a federal fill violation in which 2.2 hectares (5.4 acres) of high saltmarsh on Long Island, New York, were filled. According to these authors, quick regulatory action forced the violator to begin removal of the fill within 26 days of the violation. Since the removal was conducted in a timely fashion, much of the vegetation at original grades remained viable and no additional planting was required to complete the restoration. However, in this case the filling took place in April, just after the plants had broken dormancy, and removal was completed by May. If the filling had taken place later in the growing season, or if the fill removal was not done as promptly, replanting might have been required due to additional plant mortality.

State departments of transportation have used physical restoration as mitigation for wetland loss. In Wisconsin, twenty acres of wetland fill were removed from buried wetlands, and wet meadow plants were established on the restored site (Day 1986, Jackson 1988). This work was done as part of the Madison South Beltline project, in which the mitigation package included five acres of enhancement and 102 acres of preservation. In another case, Meiring et al. (1989) report that the Colorado Department of Highways restored a peat wetland that had been buried by wood ash and charcoal for more than one hundred years. The site, which was adjacent to a stream, was excavated down to the peat substrate and planted with willow (*Salix* sp.) cuttings. Hydrology was restored by building low check dams in the stream to raise the water table on the mitigation area.

As discussed, wetland restoration may also be required when temporary wetland fill is needed during roadway or bridge construction. The Florida Department of Transportation successfully restored 0.6 acres of emergent wetland that had been filled with material to construct a temporary road for bridge construction. After the construction was completed and the temporary fill was removed, it was noted that the natural marsh sediments had been compressed. The disturbed marsh surface was backfilled with soil to the original grade, and the site was successfully replanted (Hall and Sumanth 1989).

C.2.2.2 Hydrologic Restoration

Hydrologic restoration usually entails removing barriers that block water flow to a site or plugging drains to restore pre-existing water regimes. Josselyn and Buchholz (1984) discuss several successful marsh restorations in the San Francisco Bay area which used both physical and hydrologic restoration on diked tidal wetlands where most tidal events had been excluded. Since the lack of tidal flow and exposure to prolonged aerobic conditions had caused portions of the marsh surfaces to subside, the restoration began with the use of dredge material fill to return surface elevations physically to pre-existing ones. Tidal flow was restored to the site by creating channels and by breaching the dike. Additional native vegetation was also planted. This type of restoration effort has been successful in New Jersey (Shisler 1989), Connecticut (Steinke 1988), and

Delaware (Meredith and Saveikis 1986) for mosquito control and marsh restoration. The California Department of Transportation also used the technique successfully as mitigation for wetland fill associated with highway construction. In this instance, the dike that prevented water flow from the Elk River into the wetland was breached, restoring the hydrology. No revegetation was required as part of the permit conditions, but native vegetation has been reported to be re-establishing on the site (CALTRANS 1987).

Additional types of wetland restoration through hydrologic restoration have been demonstrated in the prairie pothole region of the midwestern United States. Idstrom (1986) suggests that in this region, the agricultural practices of ditching or tile draining wetlands so that they can be used for agricultural purposes has severely impacted the resource. Wetland restorations on these systems generally are straightforward and entail plugging the ditches and/or removing the tile drains. In many instances, a water control structure to set the maximum water level may be warranted after the drain structure has been removed (Lejcher 1986). Backfilling of canals dug for oil and gas exploration in Louisiana has also been successful (Turner et al. 1988) under some circumstances.

C.2.2.3 Biological Restoration

Biological restoration generally implies revegetation. Although such restoration is generally associated with establishing wetland plant species in conjunction with a physical or hydrologic restoration, in some instances restoring the biological component of a system may be all that is required. Re-establishment of mangroves on subtropical shorelines of Florida has been successful where grades were already appropriate for plant establishment (Banner 1977, Stephen 1983). In addition, Newling (1990) has proposed revegetating marginal agricultural wetlands to increase the acreage of bottomland hardwoods in the south.

C.2.3 RESTORATION PLAN GOALS AND OBJECTIVES

A wetland restoration plan must have clearly stated goals and objectives. In addition, it must be verified that the restoration can be achieved successfully. Hydrologic conditions may have been altered since the wetland was impacted. This could include:

- Additional impervious surface in the watershed that could cause greater volumes of water to enter the wetland than were originally present
- Reductions in surface water volumes due to diversions
- Well drawdowns that could lower the groundwater elevations
- Subsidence of the marsh surface or sea level rise

The presence of invasive plant species adjacent to the site or of large concentrations of nuisance animal species which could destroy the installed vegetation must be determined so that preventive measures can be taken (Chapter 2 and Appendix I). Additionally, the potential for vandalism should be ascertained.

C.2.4 DESIGN AND MAINTENANCE CONSIDERATIONS

Several problems can be associated with restoration projects. These include:

- Changes in the surface elevations due to compaction or subsidence
- Chemical changes due to oxidation of hydric soils

- Changes in surrounding land use that change the historic hydrology of the site

Compaction of wetland soils caused by fill is fairly common. When removing fill from a buried wetland as part of a restoration project, elevations of the original wetland surface may be below the level that will support the vegetation historically associated with the site. In tidal systems where the fill has been in place for long periods of time, sea level rise may exacerbate this problem.

Subsidence of diked wetlands may also cause surface elevations of the marsh to be lower than the current intertidal elevations. Subsidence is usually caused by the oxidation of hydric soils. When coupled with sea level rise, the diked marsh surface may be left below the elevations conducive to plant establishment. Consequently, fill will be required to achieve the elevations necessary for successful restoration. Biological benchmark data should be used to determine the appropriate elevations to use when re-establishing the wetland (Chapter 2).

Mud waves may be another problem, particularly with temporary fills. Mud waves are caused when unconsolidated sediments are squeezed upward and out from compression by fill material. A mud wave adjacent to a temporary fill site could require restoration if it significantly alters the topography of the wetland adjacent to the fill.

Restorations attempted on marshes that have been buried by dredge materials also have unique problems associated with them. Often dredge materials are composed of fine sediment particles that, after they are dewatered, are almost impervious to water. Oxidation of anaerobic dredge materials can cause chemical changes that significantly lower their pH. In addition, if the dredge material is from a saltwater environment, as the material dries, the soil salinity will increase to levels that may inhibit plant growth.

Hydrologic restoration of historic wetlands can also be problematic. Land-use changes in the surrounding area may have increased the amount of water that the restored wetland receives. Conversely, less water may now be available to the site than when it functioned as a wetland. Additionally, the quality of available water may have degraded, reducing the chances of a successful restoration. Chapter 2 describes site characteristics that must be examined before determining that wetland replacement (or restoration) is possible on that site.

C.2.5 PLANS AND SPECIFICATIONS

Several items that may often appear in the plans and specifications of a wetland restoration project may not appear in the plans and specifications of other types of wetland replacement projects. These include:

- Establishing the appropriate grade (not necessarily coinciding with the original marsh surface). Biological benchmarks adjacent to or near the restoration site should be used, if available, to establish the proper grade.

- Fill material may be required to achieve the proper restoration grade.

- Compressed mineral soils may need to be deconsolidated by plowing, discing, rototilling, or ripping before plant material can be established.

- Water control structures may be needed to restore the hydrology.

- The removal of drainage ditches, tiles, dikes, or other structures may be required to restore hydrology.

C.3 WETLAND ENHANCEMENT

Enhancement can be a valuable asset to an overall wetland replacement package. For example, wetlands within or adjacent to the proposed mitigation area may be dominated by monotypic stands of vegetation. As part of the mitigation package, ponds/open water habitat could be created in these monotypic areas to promote wildlife. While not always successful, it may be possible to remove invasive species of vegetation (e.g., *Phragmites australis*, *Lythrum salicaria*, *Phalaris arundinacea*, or *Typhus angustifolia*) and replace them with more desirable species. In both instances, the enhancement of the existing wetlands provides additional benefits to the overall mitigation plan. In areas where invasive species have colonized large tracts of land, enhancement of these sites may be acceptable in lieu of wetland replacement.

Additionally, enhancement of wetlands to create endangered species or regionally rare habitat could be an effective mitigation tool. Such enhancement could include nesting structures for the target species. Although nesting structures may be beneficial, their maintenance will have to be part of the overall long-term management plan for the site.

C.3.1 REGULATORY CONSIDERATIONS

From a regulatory perspective, the use of wetland enhancement to compensate for wetland loss has some drawbacks. Under most circumstances, the enhancement of one wetland function leads to the diminishment or loss of other wetland functions. In some circumstances, it may be hard to justify why one function is more important than another. Because of this, a wetland enhancement plan must have clearly stated goals and a strong technical argument as to why certain wetland functions should be minimized in order to improve others.

In addition, wetland enhancement used to mitigate wetland loss yields a net loss of wetland acreage, because new wetland acreage is not being created to compensate for the unavoidable loss. Instead, existing wetland acreage is being altered in some way to compensate for the loss. It is not uncommon with enhancement for the regulatory agencies to require more acreage than they would if the replacement created wetlands from uplands. Due to the regulatory problems noted above, early and close coordination with the agencies is needed before much time is spent on evaluating a potential wetland enhancement site for use as a replacement wetland.

C.3.2 WETLAND ENHANCEMENT CASE STUDIES

One of the most common types of wetland enhancement can be found in federal and state wildlife management areas. Many areas have shallow impoundments that hold water at levels conducive to waterfowl use. Although such impoundments require seasonal maintenance, if the system is properly managed and maintained, it may increase the waterfowl use of the site (Whitman and Cole 1986).

Wetland enhancement is frequently associated with the alteration of monotypic stands of wetland vegetation to improve aesthetics and wildlife use. For example, Sempek and Johnson (1987) discuss the enhancement of a cattail (*Typha latifolia*) marsh in Utah. This project involved excavating a pond, creating nesting islands, and installing vegetation in both the wetland and surrounding upland that was more conducive to wildlife use than cattails alone.

In another example, monotypic stands of tidal common reed (*Phragmites australis*) in northeastern New Jersey were eradicated with a glyphosate-based herbicide (Rodeo® by Monsanto). Afterward, marsh surface elevations were lowered through excavation, water channels were created, and waterfowl nesting islands were constructed with the excess dredge material. The site was then seeded with cordgrass (*Spartina alterniflora*) (Bontje 1988). Preliminary results indicate that this project has increased bird use of the site (Wargo 1989).

Other examples come from Department of Transportation projects that have used enhancement as part of their replacement package as well. In Washington State, 0.75 acres of fill associated with a bridge replacement was compensated for by the creation of two acres of open water excavated in existing wooded wetlands (Meehan-Martin and Swanson 1988). Although generally not approved as wetland compensation in the regulatory process, apparently the project qualified as habitat improvement (diversifying the habitat) in this case. The Research Team recommends that project sponsors minimize/avoid destruction of an existing habitat for replacement wetlands unless it is of poor quality and unless the replacement habitat will provide greater benefits to the area.

In another instance, reed canary grass (*Phalaris arundinacea*) was eliminated from existing wetlands with an herbicide, and five acres of open water ponds were created. This Wisconsin project was part of a larger replacement initiative where, in addition to the enhancement, 20 acres of wetland were restored and an additional 102 acres of wetland were preserved in perpetuity (Day 1986, Jackson 1988).

C.3.3 ENHANCEMENT PLAN GOALS AND OBJECTIVES

In any wetland replacement, the objectives of the project must be clearly stated and a determination must be made about whether the replacement goals can be achieved (Appendix J). When enhancement is used to replace the functions of an impacted wetland, several factors must be considered, including:

- The lost functions of the impacted wetland must be determined.
- The functions of the proposed enhancement wetland must be ascertained, since all wetlands have functions regardless of the impacts they have sustained (Kraus 1991).

In essence, the proposed enhancement wetland must be analyzed in terms of the impacts it will sustain in the enhancement process. This analysis must be conducted because of the great potential for reducing or eliminating certain functions in the process of enhancing others.

After the impacts on both the wetland lost to construction and the wetland proposed for enhancement have been determined, it must be ascertained whether the enhancement will replace all of the lost functions from all of the impacts. Exceptions may be circumstances where the enhancement wetland is designed to establish a rare wetland type for the region or an endangered species habitat. Under either circumstance, strong technical support must be provided and regulatory concurrence must be obtained.

C.3.4 DESIGN AND MAINTENANCE CONSIDERATIONS

There are several items to consider when planning an enhancement project. These include maintenance of water control structures and wildlife nesting structures, as well as the control of re-invading plant species and undesirable wildlife. Generally, in an enhancement project that includes eradicating undesirable plant species, not all invasive plants from the region will be eliminated. Therefore, it is possible that the enhancement site could be re-invaded. Routine monitoring and removal of undesirable plants may be required in the overall site management plan. In addition, wetland enhancement is usually designed to attract wildlife. Unfortunately, the newly established habitat may attract larger numbers of individuals of a given species than the site can support. Excessive numbers of deer, muskrat, nutria, geese, or carp can destroy established vegetation faster than it can recolonize. In addition, geese and muskrat can deconsolidate the substrate with their feeding activities. After deconsolidation, the substrate may no longer have the structural stability to support vegetation.

C.3.5 PLANS AND SPECIFICATIONS

Several items often may appear in the plans and specifications of a wetland enhancement project which may not necessarily appear in the plans and specifications of a wetland replacement project, including:

- The timing and use of herbicides to effectively eradicate nuisance plant species
- Long-term site maintenance to assure that nuisance plant species do not re-establish
- Construction and maintenance of wildlife nesting structures (For specific plans and specifications on the construction of wildlife nesting structures, see Henderson 1981, Kress 1985, and Yoakum et al. 1980.)
- Size and placement of logs, rocks, or other materials to create habitat (Gore 1985)
- Construction and placement of snags in ponds, lakes, or streams (Gore 1985)
- Construction and placement of riffles and pools in streams (Gore 1985)
- Construction and maintenance of dams and water control structures

C.4. REFERENCES CITED

Banner, A. 1977. Revegetation and maturation of a restored shoreline in the Indian River, Florida, pp. 13-33. In R. Lewis and D.P. Cole (Eds.), Proceedings of the Fourth Annual Conference on Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Bontje, M.P. 1988. The application of science and engineering to restore a saltmarsh, 1987, pp. 16-23. In F.J. Webb (Ed.), Proceedings of the Fifteenth Annual Conference on Wetlands Restoration and Creation. Hillsborough Community College, Tampa, Florida.

CALTRANS. 1987. Environmental Study, Elk River Mitigation Project. #01-HUM-101-74.5. California Department of Transportation. 18 pp.

Day, E.A. 1986. Mitigation for the South Madison Beltline, Dane County, Wisconsin. Wisconsin Department of Transportation. 52 pp.

Gore, J.A. 1985. The Restoration of Rivers and Streams, Theories and Experiences. Butterworth Publishers, Boston, Massachusetts. 280 pp.

Hall, W.C. and M.N. Sumanth. 1989. Determination of Effectiveness of Required Environmental Mitigation Activities Related to the Construction of Highways in Florida. Report # FL/DOT/SMO/89-347. Florida Department of Transportation. 131 pp.

Henderson, C.L. 1981. Woodworking for Wildlife - Homes for Birds and Mammals. State of Minnesota Department of Administration, Print Communications Division, St. Paul, Minnesota. 47 pp.

Idstrom, J. 1986. A field manager's experience with wetland restoration, pp. 29-32. In J.L. Piehl (Ed.), Wetland Restoration –A Techniques Workshop. Minnesota Chapter of the Wildlife Society, Fergus Falls, Minnesota.

Jackson, J.O. 1988. Preliminary Report on Wetland Planting and Seeding Evaluation for the Madison South Beltline Mitigation Project 1988. Wisconsin Department of Transportation Report. 18 pp.

Josselyn, M. and Buchholz, J. 1984. Marsh Restoration In San Francisco Bay–A Guide to Design and Planning. Technical Report # 3. The Paul F. Romberg Tiburon Center for Environmental Studies, Tiburon, California. 103 pp.

Kraus, M.L. 1991. The unsung virtues of an urban wetland. National Wetlands Newsletter 13(1):8-9.

Kress, S.W. 1985. The Audubon Society Guide to Attracting Birds. Charles Scribner's Sons, New York. 377 pp.

Kruczynski, W.L. 1989. Options to be considered in preparation and evaluation of mitigation plans, pp. 143-158. In J. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Volume II. U.S. Environmental Protection Agency, Corvallis, Oregon.

LaPerriere, A.J. and Farmer, M.M. 1988. Anatomy of a high marsh restoration effort, pp. 172-184. In F.J. Webb (Ed.), Proceedings of the Fifteenth Annual Conference on Wetlands Restoration and Creation. Hillsborough Community College, Tampa, Florida.

Lejcher, T. 1986. Hydrology and watershed considerations, pp. 4-9. In J.L. Piehl (Ed.), Wetland Restoration–Techniques Workshop. Minnesota Chapter of the Wildlife Society, Fergus Falls, Minnesota.

Lewis, R.R. 1989. Wetlands restoration/creation/enhancement terminology: suggestions for standardization, pp. 103. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Volume II. U.S. Environmental Protection Agency, Corvallis, Oregon.

Meehan-Martin, P.J. and Swanson, D. 1988. North River Bridge Replacement SR101 Wetland Monitoring Report # L-7934. Washington State Department of Transportation. 8 pp.

Meiring, K.J., J.D. Von Loh, and D.J. Cooper. 1989. Hoosier Creek Wetland Replacement. Report # FR 285-4(23). Colorado Department of Highways. 22 pp.

Merideth, W.H. and D.E. Saveikis. 1986. Effects of open marsh management (OMWM) on bird populations of a Delaware Bay tidal marsh, and OMWM's use in waterbird habitat restoration and enhancement, pp. 298-321. In W.R. Whitman and W.H. Merideth (Eds.), Waterfowl and Wetlands Symposium: Proceedings of a Symposium on Waterfowl and Wetlands Management in the Coastal Zone of the Atlantic Flyway. Delaware Coastal Management Program, Delaware Department of Natural Resources and Environmental Control, Dover, Delaware.

Mish, F.C. (Ed.). 1989. The New Merriam-Webster Dictionary. Merriam-Webster, Inc. 891 pp.

Newling, C.J. 1990. Restoration of bottomland hardwood forests in the lower Mississippi Valley. Restoration and Management Notes 8(1):23-28.

Sempek, J.E. and C.E. Johnson. 1987. Wetlands enhancement at the Ogden Nature Center in Ogden, Utah, pp. 161-165. In K.M. Mutz and L.C. Lee (Eds.), Wetlands and Riparian Ecosystems of the American West: Eighth Annual Meeting of the Society of Wetland Scientists Proceedings. Seattle, Washington.

Shisler, J.K. 1989. Creation and restoration of coastal wetlands of the northeastern United States, pp. 145-165. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Volume I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Steinke, T.J. 1988. Hydrologic manipulation and restoring wetland values: Pine Creek, Fairfield, Connecticut, pp. 377-383. In J.A. Kusler and M.L. Quammen (Eds.), Proceedings of the National Wetland Symposium: Mitigation of Impacts and Losses. Association of State Wetland Managers Technical Report # 3. Berne, New York.

Stephen, M.F. 1983. Mangrove restoration in Naples, Florida, pp. 202-216. In F.J. Webb (Ed.), Proceedings of the Tenth Annual Conference on Wetland Restoration and Creation. Hillsborough Community College, Tampa, Florida.

Turner, R.E., I.A. Mendelssohn, K.L. McKee, R. Costanza, C. Neill, J.P. Sikora, W.B. Sikora, and E. Swenson. 1988. Backfilling canals in coastal Louisiana, pp. 377-383. In J.A. Kusler and M.L. Quammen (Eds.), Proceedings of the National Wetland Symposium: Mitigation of Impacts and Losses. Association of State Wetland Managers Technical Report # 3. Berne, New York.

Wargo, J.G. 1989. Avian Species Richness: A Natural Marsh vs. an Enhanced Marsh. M.S. Thesis. Rutgers University, New Brunswick, New Jersey. 95 pp.

Whitman, W.R. and R.V. Cole. 1986. Ecological conditions and implications for waterfowl management in selected coastal impoundments of Delaware, pp. 98-119. In W.R. Whitman and W.H. Merideth (Eds.), Waterfowl and Wetlands Symposium: Proceedings of a Symposium on Waterfowl and Wetlands Management in the Coastal Zone of the Atlantic Flyway. Delaware Coastal Management Program, Delaware Department of Natural Resources and Environmental Control, Dover, Delaware.

Yoakum, J., W.P. Dasman, H.R. Sanderson, C.M. Nixon, and H.S. Crawford. 1980. Habitat improvement techniques, pp. 329-403. In S.D. Schemnitz (Ed.), Wildlife Management Techniques Manual, 4th Edition.

APPENDIX D
WETLAND TYPES

In addition to the references cited at the end of this appendix, authors contacted the individuals listed below about their expertise on various wetland replacement topics. These contacts are noted in the text parenthetically as "(NAME personal communication)."

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A wetland's type can be described by observing its vegetative community and/or its hydrology. Vegetation depends on hydrology and, therefore, its presence usually reflects "current" hydrology at the site unless the hydrology has been altered recently. The duration of inundation/saturation, depth of inundation, flow, periodicity (frequency), and chemistry of water have been cited as "the most important determinants of the character and function of a wetland" (Larson 1988). In wetland replacement or restoration, the wetland type is controlled by establishing the correct hydrology to support a desired plant community, because vegetation has a significant impact on wetland functions. Because the *Guidelines* are for the construction of wetlands, the types will be explained in terms of their hydrology. Vegetation can be organized in relation to this hydrology. When objectives require that a specific plant community be created, the hydrology necessary to support that community must be established first.

The U.S. Fish and Wildlife Service (FWS) (Cowardin et al. 1979) has developed a classification system that takes aspects of hydrology and vegetation into account. However, under its hierarchical system they are not primary considerations. While this classification system is very useful for mapping wetland types and understanding the ecology of the entire system, it is not as useful for identifying the critical factors that dictate what type of wetland should be constructed. The modifiers used to describe water regimes are not objective enough for setting specific goals on which technical designs can be based. The most detail that the FWS System contains for vegetation is a mention of dominant species. However, when wetland vegetation is to be planted as part of a project, more than the dominant species must be discussed, as shown in the following discussion of the various wetland types.

D.1 TIDAL WETLANDS (SALTWATER AND FRESHWATER)

Tidal wetland types are characterized by salinity; it determines which plant species will grow, i.e., the diversity of species that a tidal wetland will support. As the salinity decreases, diversity generally increases (Gosselink 1984 and Odum and Hoover 1988).

D.1.1 TIDAL ZONES

The frequency and duration of flooding in any portion of a tidal wetland is determined by its relationship to mean sea level. Plant communities depend on this relationship. Species grow in particular zones according to the frequency of tidal inundation. Therefore, these zones can be defined by water levels and the plant species associated with them. The construction of tidal wetlands involves establishing elevations that will achieve the frequency of inundation necessary to establish a particular plant community. (See Appendix E for information on creating hydrology.)

Typical tidal inundation zones and their characteristic vegetation are described below. Although the FWS Classification System (Cowardin et al. 1979) is not discussed in depth in the *Guidelines*, the tidal water regime modifiers that most closely resemble the zones defined below are given in Table D-1.

TABLE D-1

TIDAL ZONES IN RELATION TO THE FWS CLASSIFICATION SYSTEM[1]

Tidal Zone	U.S. FWS Equivalent
Above Mean High Water (> MHW)	Irregularly Flooded
Mean High Water to Mean Low Water (MHW - MLW)	Regularly Flooded
Below Mean Low Water (< MLW)	Irregularly Exposed (From MLW to Spring Low Water)
	Subtidal (Below Spring Low Water)

1 Cowardin, et al. 1979

D.1.1.1 Above Mean High Water

The section of a tidal wetland not normally flooded during the daily tidal cycle is the area above Mean High Water (MHW). This area floods only during spring tides or storm tides and, therefore, has a very different plant community than the area below MHW. When only grasses and forbs are present, this area is most commonly known as "high marsh." The plants found in this area can include grasses, forbs, shrubs, and trees.

It should be noted that the Pacific coast of the U.S. has a mixed tidal cycle. The two daily high tides are at substantially different elevations, the higher of which more closely resembles MHW in areas without a mixed tidal cycle. Plant communities reflect the two daily levels of flooding in wetlands of the Pacific coast.

D.1.1.2 Mean High Water to Mean Low Water

The area between MHW and Mean Low Water (MLW) is the intertidal area, the portion flooded and exposed for some period every day.

Plant species generally adapt to the physical and competitive conditions in only a portion of the intertidal area. The entire area, generally called "low marsh," has its own associated plant community, but many species within this community survive only within a particular elevation range, which can be identified for each species through the use of biological benchmarks (Chapter 2). Grasses and forbs are the most common types of vegetation in this range, but some shrubs can survive in these conditions. In Florida, for example, the red mangrove (*Rhizophora mangle*) grows in the upper portion of this zone.

D.1.1.3 Below Mean Low Water

The area below Mean Low Water is always flooded, except during extremely low tides. Very few emergent species survive in this area. The type of vegetation most frequently found here is submerged aquatic vegetation. The turbidity of the water is an important limiting factor on which species, if any, will grow below MLW. The degree of wave energy also strongly influences what type of vegetation will survive here and in the intertidal area.

D.1.2 LEVEL OF DIFFICULTY IN CONSTRUCTION

The design and construction of tidal wetlands is the most reliable kind of wetland replacement. Their hydrology is dependable and well understood: the water supply is virtually unlimited and the tidal cycle is predictable. Therefore, the chances for success of a properly designed and constructed project are high.

While water levels are somewhat predictable in tidal systems, some factors—in addition to lunar cycles—can have a substantial influence on them. For example, wind effects can dominate water levels; streamflow or stormwater runoff into a tidal area can alter water levels and salinity. The best way to take these factors into account is to use biological benchmarks, which are vegetational indicators that identify historical water and salinity levels (Chapter 2). Elevations for a desired community can be duplicated from a reference wetland to the replacement wetland, and a similar community can develop. Determining and establishing these elevations is relatively straightforward.

D.1.3 REGIONAL TYPES AND CONSIDERATIONS

The following sections contain information about special regional types of tidal wetlands. Due to their unique nature, these wetlands may require special attention and techniques in their construction. Tidal wetland types are included in this discussion only if practical information based on field work exists for the type. Local experts should be consulted for the most current technologies when working in special wetland types.

D.1.3.1 Mangrove Forests

Mangroves forests are found in the southern half of Florida. These limits are due to the species' intolerance of freezing temperatures (Odum et al. 1982). Three species of mangrove are used in wetland creation in this area: the Black mangrove (*Avicennia germans*), the Red mangrove (*Rhizophora mangle*), and the White mangrove (*Laguncularia racemosa*). Red mangroves generally occupy fringe or riverine environments characterized by active water flow and high flushing. The other two species are dominant in stagnant environments where water flows are reduced and often seasonal (Cintron-Molero 1992). The Black mangrove extends slightly farther north and along the Gulf of Mexico. It is the most tolerant of the species and is dominant in areas subject to high substrate salinity or frost events (Cintron-Molero 1992).

One of the most important factors in successfully establishing mangroves is placing them at the correct elevation. Although this applies to all tidal vegetation, there is a lack of agreement about the proper elevations for planting mangroves (Lewis 1989). The most success has been documented with mangroves planted at the following elevations (Lewis, personal communication):

Rhizophora mangle:	Upper 20% of the intertidal area (MHW-MLW)
Avicennia germinans:	MHW to 1 foot above MHW
Laguncularia racemosa:	MHW to 1 foot above MHW

For more complete information regarding proper planting elevations, Crewz and Lewis (1991) evaluate mangrove planting projects as well as other emergent vegetation establishment projects in Florida.

Another critical factor in the success of mangrove forests is wave energy. Lewis (1989) notes that it is well documented that mangroves are not suitable for exposed or eroding shorelines that lack offshore protection.

Teas (1977) reports that mangroves grow in salinities ranging from .02 ppt to greater than 60 ppt and that they seem to be most vigorous in estuaries where salinities fluctuate. While mangroves tolerate high salinities, if salt levels are too high due to a lack of tidal flushing, they will be negatively affected (Lewis 1989). Other factors impacting success are excessive wave or current exposure; unsuitable substrate; excessive temperatures; and excessive damage by flotsam, wrack accumulations, infestations, grazing, trampling, and vandalism (Cintron-Molero 1992).

Lewis (1989) identifies four types of mangrove plantings: propagules, one- to two-year-old seedlings, three- to five-year-old nursery-grown trees, and field-collected transplants. Which type to use varies with site conditions and project objectives.

D.1.3.2 Seagrass Meadows

Seagrass meadows are not restricted to a particular region of the country; rather, they grow in tidal waters of most coastal marine states, except in Georgia and South Carolina (Fonseca 1989, 1992). Most seagrasses grow below mean low water (MLW), but their actual distribution and seaward limits depend on species, competition, and water quality parameters, such as turbidity, salinity, and temperature (Zieman and Zieman 1989).

Fonseca (1989, 1992) reports that the most difficult aspect of seagrass-meadow mitigation projects can be site selection. Creating new seagrass beds where they have not previously existed is very difficult. Fonseca recommends using previously impacted or destroyed areas as sites. If this is impossible and the only available site is one where seagrasses do not already exist, project sponsors should determine whether conditions are present which may permit or prevent the natural colonization of these plants. Certain environmental conditions may have a harmful impact on plantings if not corrected. These special site considerations can hold serious implications for seagrass replacement and overall project success:

- **Water quality:** Suspended sediments have a high impact on depth of light penetration (intensity and duration of exposure), which seagrasses depend upon. Wave energy, tidal currents, and sediment size all can affect turbidity (Fonseca 1989), as can sediment runoff from erosion.

- **Wave energy:** This factor can affect the form of the bed (waves or currents can cause patches of unvegetated areas) or prevent establishment of new plants (Fonseca 1989).

- **Depth of deconsolidated sediment:** While seagrasses can survive in sediments that range in texture from fine mud to coarse sand (Zieman and Zieman 1989), they do require a sufficient depth for root growth (Lewis 1987 and Zieman and Zieman 1989). Lewis (1987) recommends a depth of at least 60 cm of sufficiently deconsolidated sediment.

- **Animal influence:** Animal influence is a consideration regardless of wetland type (Appendix I), including establishment of seagrass meadows. Lewis (1987) reports that bioturbation of burrowing animals (such as *Callianassa*, a large, burrowing callianassid shrimp) can severely impact water quality. Lewis notes that in areas where seagrass meadows have recently been impacted, successful revegetation may be possible in the absence of shrimp. But if shrimp are present in colonies where density reaches approximately 16 burrows per square meter, revegetation may fail.

There are also a number of factors critical to construction which deserve special mention for this type of replacement. Timing of planting, while important for all revegetation projects (Appendix G), can be very important in seagrass planting because of the need for rapid spread. After some seagrass plants have flowered, the reproductive shoot dies. Thus, it is important that planting take place before this flowering if spreading of the species is an issue (Fonseca 1989).

Fonseca (1989) lists four species that have been experimented with/used in projects enough to consider them reliable possibilities for revegetation projects:

Thalassia testudinum	Turtle grass
Halodule wrightii	Shoal grass
Syringodium filiforme	Manatee grass
Zostera marina	Eelgrass

Fonseca (1989, 1992) and Kirkman (1992) cite a number of references for the specifics of seagrass planting. A variety of transplants and methods of stabilization can be considered, depending on the site conditions. One of the most important aspects of seagrass revegetation is that newly planted sites be protected from impacts (sediment inflow, wave energy, etc.) until they have sufficient time to establish.

D.2 NONTIDAL FRESHWATER WETLANDS

Nontidal, freshwater wetlands can be characterized by the duration (inundation/saturation), depth of flooding and frequency, and the depth of saturation from the surface. Which plant species establish and compete in an area depends on inundation (and saturation), frequency, and drainage patterns (Klimas 1988). Controlling duration by manipulating local hydrology will create an environment for particular wetland types, defined below. Therefore, the vegetative community can also be controlled in wetlands flooded for long durations by regulating water levels within this environment.

D.2.1 TYPES

This section groups wetlands according to the duration that they are inundated or saturated. All of the plants that occur in a particular wetland type defined by flood duration have adapted to those hydrologic conditions.

The community that results under these conditions carries out specific functions (such as a particular habitat). The dependence of vegetation on hydrology and the importance of hydrologic manipulation in wetland construction (Appendix E) makes the separation of plants into hydrologic groups a practical method of organization.

For reasons previously stated, the FWS system (Cowardin et al. 1979) is not used for the purposes of the *Guidelines*. The nontidal water regime modifiers defined in FWS that are most likely equivalent to the wetland types defined below have been indicated for each zone and summarized in Table D-2.

Many wetland areas consist mainly of only one of the wetland types defined below. It should be noted, however, that wetlands also contain a transition area (sometimes referred to as a fringe) from the primary wetland type to upland. This transition region will contain one or more areas that fit the definitions of the other wetland types listed.

TABLE D-2

SUMMARY OF WETLAND TYPE DEFINITIONS AND U.S. FWS EQUIVALENTS

Wetland Type [1]	Portion of *growing season* water is at or above ground surface [1]	U.S. FWS Equivalent [2]
Permanently to Semipermanently Saturated or Inundated	75 - 100%	Permanently Flooded, Intermittently Exposed, Semipermanently Flooded
Regularly Saturated or Inundated	25 - 75%	Saturated
Seasonally Saturated or Inundated	12.5 - 25%	Seasonally Flooded, Temporarily Flooded
Irregularly Saturated or Inundated	5 - 12.5%	Intermittently Flooded

1 Adapted from Environmental Laboratory 1987
2 Cowardin, et al. 1979
Note: Because the FWS Classification System does not describe its modifiers in finite numerical terms, they cannot be definitively expressed in the same terms as the wetland types. As a result, the equivalents given here are approximate.

D.2.1.1 Permanently to Semipermanently Saturated or Inundated Wetlands

Wetlands that are permanently to semipermanently saturated or inundated have water at or above the ground surface from 75% to 100% of the growing season (adapted from Environmental Laboratory 1987). Under the classification system developed by the U.S. Fish and Wildlife Service (Cowardin et al. 1979), the water regimes "Permanently Flooded, Intermittently Exposed, and Semipermanently Flooded" generally would all fit under this wetland type.

This duration of flooding plays a part in determining the type of wetland that can be established. Only specially adapted plant species tolerate this length of time under anaerobic conditions. Examples of these wetlands include submerged aquatic bed, marsh, scrub-shrub wetland, and forested wetland.

The final hydrological factor for selection of plant community is depth of water. Most submerged aquatic vegetation requires a specific water level above the ground surface in order to survive. Many emergent species that can survive in two inches of water cannot tolerate water depths of two feet. Some species (e.g., many *Carex* species) compete best when water is high in the early part of the growing season but low in the summer (Powers, personal communication).

D.2.1.2 Regularly Saturated or Inundated Wetlands

Wetlands that are Regularly Saturated or Inundated have water at or above the ground surface from 25% to 75% of the growing season (adapted from Environmental Laboratory 1987). This is a wide range of possible durations, but the plant communities supported are similar in that:

- They do not ordinarily tolerate permanent flooding
- They compete better when there is a significant period of inundation or saturation

Under Cowardin's classification system (1979), this type would generally include the "Saturated" water regime modifier.

Vegetation communities found in this wetland type would be similar to those listed under Permanently to Semipermanently Inundated or Saturated (submerged aquatic bed, marsh, scrub-shrub wetland, and forested wetland). Depth is, again, the final selective hydrological factor for what specific communities a wetland will support when flooded to this extent.

D.2.1.3 Seasonally Saturated or Inundated Wetlands

Wetlands that are Seasonally Saturated or Inundated have water at or above the surface from 12.5% to 25% of the growing season (adapted from Environmental Laboratory 1987). Under Cowardin's classification system (1979), this type of wetland would generally include those with water regime modifiers "Seasonally Flooded" and "Temporarily Flooded."

Vegetation types that would grow under these conditions are marsh, scrub-shrub, and forested communities. The specific flood frequency, duration, and timing as well as regional location would be factors determining which species could be supported. In many cases, because of the shorter period of inundation, depth of water during flooding may not be a significant factor in determining which species will grow on the site (Garbisch, Clewell, personal communications). For wetlands that flood for only a portion of the growing season, however, the timing of that flooding can be critical to species selection. Some plants that leaf out late in the season can tolerate flooding only at the beginning of the season when they are dormant (Broadfoot and Williston 1973).

D.2.1.4 Irregularly Saturated or Inundated Wetlands

Wetlands that are Irregularly Saturated or Inundated have water at or above the surface between 5% and 12.5% of the growing season (adapted from Environmental Laboratory 1987). Under Cowardin's classification system (1979) this would generally be described by the water regime modifier "Intermittently Flooded." Vegetation types that occur in these conditions are marsh, scrub-shrub, and forested communities.

Depth may not be as critical in this hydrologic type for determining which species will occur under this duration of flooding (Garbisch unpublished). The flood duration is short enough, in fact, that this type may sometimes be a transition to upland and may not be classified as a wetland. Many drought tolerant and/or upland species survive under these conditions. The time during the growing season that the flooding occurs, however, is still a relatively important selective force for plant species.

D.2.2 LEVEL OF DIFFICULTY

The ease or difficulty of constructing successful nontidal, freshwater wetlands depends on the water source: the better the hydrology is understood, the more predictable it becomes. In order to predict hydrology, all of the variables that affect that source must be known and understood. For the same reason that tidal wetlands are the least difficult to design based on hydrology, nontidal wetlands can be some of the most difficult. While tidal waters are well understood and their fluctuations have been predicted and charted, some nontidal hydrologic systems are very poorly understood.

The following hydrology types are described from the least difficult to the most difficult to establish:

- **Lakes or large river systems:** Wetlands with water supplied by large lake systems or large river systems are some of the least difficult nontidal systems to construct. The hydrology in these areas is often understood and is reliable and predictable. Patrick (1981) states that wetlands controlled by the water from a large system may not have significant hydraulic coupling with the surrounding uplands. In other words, in a large system, high precipitation or drought in uplands adjacent to a wetland does not necessarily mean a corresponding rise or drop, respectively, in water levels. Much of the baseline information needed to design wetlands in these areas is available through the Water Resource Division of the U.S. Geologic Survey. Lengthy, detailed studies often are not necessary. Biological benchmarks can be used in these systems for reliable elevation references (Chapter 2).

- **Intermittent and perennial streams:** The hydrology associated with intermittent and perennial streams may not be as regular and reliable as that of large rivers and lakes and the hydrologic base line information may not be available. The design of wetlands that rely on this kind of water source is more difficult because of the scarcity of reliable information and the larger number of variables that affect water levels.

- **Surface runoff:** Wetlands that rely on surface runoff can be difficult to design reliably, compared to the surface water sources described above. Watershed analysis and runoff calculations (Appendix E) can assure the selection of a replacement site that will work under normal or average meteorological conditions. However, unexpected and uncontrolled periods of drought or flooding could cause the project to be unsuccessful.

- **Groundwater:** The most difficult type of wetland to design with existing technology is one that runs on groundwater. This water source is the least understood and the most difficult to predict quantitatively. Even with extensive groundwater studies (Appendix E), wetlands with only this water source are difficult to design reliably.

In numerous situations, a project would involve the use of more than one of the water sources discussed above. In this case, every variable must be taken into account to predict accurately how much water is available for how long. As the number of variables affecting the system increases and/or the understanding of that system decreases, the level of difficulty in the design and construction of wetlands increases. However, using more than one source of hydrology when designing replacement wetlands may improve the chances of success.

D.2.3 REGIONAL TYPES AND CONSIDERATIONS

The following sections contain information regarding specific wetland types that are either limited to certain regions of the country or occur only in very specific environments throughout the country. They deserve attention because special considerations may be necessary for their construction.

Information for this section was obtained from personal communication or papers on the construction of the particular wetland types. Information that is lacking is usually due to the many gaps in understanding about wetland replacement. As more technical information becomes available from successful completion of projects, it may be added to this document in the form of supplements.

Information about major problems and reasons for failure for each type are presented in each section. In most cases these problems relate to establishing the correct hydrology. Detailed guidelines for the proper installation of the correct hydrology can be found in Appendix E of this document.

D.2.3.1 Prairie Potholes or Prairie Basin Wetlands

The glaciated prairie region, characterized by numerous undrained depressions, is represented in southern Alberta, southern Saskatchewan, extreme southwestern Manitoba, extreme northeastern Montana, northern and east-central North Dakota, eastern South Dakota, small portions of western Minnesota, and northwestern Iowa (Stewart and Kantrud 1971).

Kantrud et al. (1989) describe prairie basin wetlands as basins (depressions capable of holding surface water) which are underlain by hydric soils and, when surface water is present, can support hydrophytes. They can occur as any of the four wetland types described in Section D.2.1 and can consist of more than one type. Stewart and Kantrud (1971) devised a classification system specifically for describing ponds and lakes in the glaciated prairie region which contains vegetational zones that correspond to the wetland types discussed in this appendix.

- **Wetland-low-prairie zone** (corresponds with Irregularly Saturated or Inundated): surface water ordinarily maintained for only a brief period in the early spring before the bottom ice seal melts

- **Wet-meadow zone** (corresponds with Seasonally Saturated or Inundated): surface water usually maintained for only a few weeks after the spring snowmelt and occasionally for several days after heavy rainstorms in late spring, summer, and fall

- **Shallow-marsh zone** (corresponds with Regularly Saturated or Inundated): normally maintains surface water for an extended period in spring and early summer but is frequently dry during late summer and fall

- **Deep-marsh zone** (corresponds with Semipermanently to Permanently Saturated or Inundated): ordinarily maintains surface water throughout the spring and summer and frequently maintains surface water into fall and winter

Stewart and Kantrud (1971) also describe vegetation types that characterize these hydrologies, but because of the methods used in this region for restoration and creation, it is not important to discuss vegetation here.

In the Prairie Pothole Region, restoration of potholes is accomplished by removing drainage systems and allowing the return of the original hydrology. This is accomplished by filling drainage ditches or removing tile drainage systems. With the return of this hydrology, typical pothole vegetation recolonizes the site (Swanson, Shumler, personal communications). Appendix C contains more information regarding restoration. For the most recent information and experience on restoring prairie pothole wetlands, *Guidelines* users should review Galatowitsch and van der Valk (1994).

Wetland creation in this region has been accomplished by excavating depressions and backfilling to design grades with topsoil (Shumler, Larson, personal communications). Generally, it is important in this area of the country to backfill with upland topsoil because in excavating a subsoil of solid yellow clay is usually encountered in which nothing will grow (Turnow, personal communication). The site is then allowed to volunteer with typical prairie pothole vegetation. The most difficult aspect of this construction is establishing a specific hydrology (i.e., pool level, duration, etc.).

It has been suggested that inoculating these restored or created depressions with sediment from another pothole may be an effective method of revegetating the area (Hubbard, personal communication). However, using seed banks to revegetate areas, especially when hydrology is not predictable, has its own disadvantages (Appendix F, Section F.4.3, Implications for Using Soil Seed Banks).

D.2.3.2 Vernal Pools

Zedler (1987) defines the vernal pool as "a natural habitat of the Mediterranean climate region of the Pacific coast covered by shallow water for extended periods during the cool season but completely dry for most of the warm season drought." The region in which this Mediterranean climate exists is known as the California Floristic Province and ranges from northern Baja California to southern Oregon, extending inland to the summits of the higher mountains (Zedler 1989). This habitat produces conditions that allow the growth of only specialized vegetation. Plants must be able to endure both flooding and drought or be able to grow and reproduce during the short period of time that conditions are favorable (Zedler 1987). Some species that grow in vernal pools are endemic to the habitat in that region (Zedler 1987, Ferren and Pritchett 1988).

Vernal pools can be Seasonally or Irregularly Saturated or Inundated, as defined in Section D.2.1. Pools which are seasonally flooded usually have irregularly flooded outer edges.

Zedler (1987) reports that "Vernal pools are found only where there is a seasonally perched water table." The occurrence of a substrate that precludes the infiltration of water to the actual water table seems vital to successful creation of this wetland type. Ferren and Pritchett (1988) report that a critical component of the pre-project monitoring phase of their vernal pool creation was identifying a subsoil layer containing clay, which indicated that the area potentially had poor permeability. They go on to say that "a high clay content indicates low hydraulic conductivity and thus low subsurface flow and high moisture storage capacity." They suggest that locating replacement sites adjacent to naturally occurring pools may increase the probability of soils being suitably impermeable for vernal pool creation. However, Ferren and Gevirtz (1990) point out that regional differences in vernal pools indicate that all pools may not contain the same substrate characteristics. They explain that some seasonal seeps, which imply groundwater interaction, are referred to as vernal pools. This contradicts Zedler's (1987) definition.

Unlike most wetland types, the most successful method found for plant establishment in vernal pools has been the inoculation of created depressions or impoundments with topsoil from existing vernal pools, preferably those which are scheduled to be impacted (Zedler, Skordal, personal communications). Seed collection and use in excavated depressions has been attempted by Huffman and Associates of Sacramento, California (Skordal, personal communication). Preliminary results indicate that after one growing season, seeded areas did significantly worse than those inoculated with salvaged topsoil. The second year of growth in seeded pools was somewhat better. Salvaged topsoil contains a seed bank which, when placed in conditions identical to those from which it was removed, may produce a similar community. Because it is difficult to replicate conditions that are not well understood, seed bank use can be unpredictable. (See Appendix F for information on seed banks.)

Water levels can be manipulated in vernal pools, as in other wetland types, to prevent the growth of undesirable species. In California at the Del Sol Open Space project in Santa Barbara, pools were designed to be deeper than natural pools to prevent growth of *Lolium multiflorum*, an invasive, introduced grass

(Ferren and Pritchett 1988). When water levels in the created pool differ from levels in the topsoil source pool, however, ability to predict species decreases.

Different zones of flood duration within the pools support different pool species (Ferren and Pritchett 1988). However, the special effort to duplicate these specific zones by separately salvaging topsoil from one zone of a pool and spreading it only over a portion of the created pool with identical hydrology has been determined to be unnecessary (Zedler, personal communication). Zedler remarks that zonation of species takes place independently of the location of topsoil placement. The slopes are so slight and areas of species' dominance so small that it is not necessary to isolate topsoil from specific zones.

There is a lack of long-term results from vernal pool creation projects. Ferren and Gevirtz (1990) suggest that vernal pool restoration and creation should be viewed as experimental because of the lack of definitive information and because of the number of observed failures. Increased understanding of these systems is necessary before their creation can be used to replace losses. They point out that only recently has it been fully realized that a great diversity of habitats are termed "vernal pools." As is the case with other wetland types, "observations on or conclusions drawn from the results of a habitat manipulation experiment, or mitigation for impacts to one type of vernal pool habitat, may not be transferable to another region" (Ferren and Gevirtz 1990).

D.2.3.3 Northern Peatlands

Nilsson et al. (1990) state that the characteristic that distinguishes peatlands from other wetland types is that peatlands accumulate partially decomposed vegetation, or "peat." Clausen and Brooks (1980) report that peatland water tables rise rapidly after the spring thaw, stay near the surface during the spring, and drop rapidly in late summer, when the water table stabilizes and remains at a low level through winter. Generally, peatlands can be classified by the wetland type (described in Section D.2.1) Regularly Saturated or Inundated, although some peatlands, or portions of peatlands, may experience Permanent to Semipermanent Saturation or Inundation.

Most peatland work being done in North America is the reclamation of mined peatlands (Famous, Berglund, personal communication). This is accomplished by restoring the hydrology that was removed to mine peat. It is sometimes necessary to block not only the main drainage ditch for the site but also to build obstructions in intermediate ditches within it to restore hydrology to the entire site (Berglund, personal communication). The area is then allowed to revegetate. Nilsson et al. (1990) suggest that propagule introduction may accelerate revegetation and control species types.

Peatlands can be characterized as follows by their source of hydrology and corresponding nutrient level:

- **Ombrotrophic bogs:** peatlands that receive only precipitation and, therefore, have low nutrient input
- **Minerotrophic fens:** peatlands which are supplied with ground water and/or surface water as well as precipitation, and hence, receive more nutrients

The level of inflow of nutrients affects how quickly the peatland will revegetate (Nilsson et al. 1990, Berglund, personal communication). Nilsson et al. suggest that soil amendments (e.g., sand, boiler ash, sludge, fertilizers, or lime) increase the rate of revegetation. Twaroski and Kurmis (1982) found that application of certain fertilizers (e.g., potassium) had significant effects on seeded grass.

D.2.3.4 Southeastern Forested Wetlands

The southeastern region includes the area from Virginia to Arkansas south to Florida and Louisiana (Clewell 1989). Clewell broadly defines eight forested wetland vegetation types. He includes information on flood duration where possible; however, some types have varying water regimes. Although many type names are recognized for forested wetlands, Clewell's can be generally applied. These types are summarized in Table D-3. While this summary lists only a few species or typical kinds of vegetation, Larson (1981) lists a number of forest types in relation to soil moisture regime, which roughly correspond to wetland types described in Section D.2.1.

Clewell (1989) lists several critical factors for the successful establishment of forested wetland projects, such as:

- Establishment of the correct hydrology
- Minimization of substrate erosion
- Adequate rooting volume
- Soil fertility
- Noxious plant control
- Herbivore control

These are critical factors for most wetland creation projects. Hook (1988) presents evidence that the water tolerance of some species can vary with soil type, moving versus standing water, and siltation. Hook also points out that most seeds of tree species will not germinate under water, and uses a study by DeBell and Naylor (1972) on Swamp tupelo as an example. Because of this, if seeding tree species is the method of plant establishment, it is important that water recede during the germination period. Site contouring or stream creation may be necessary to supply proper hydrology. Substrate stabilization is especially important when creating forested wetlands because of the slow growth of trees, which results in uncovered ground for an extended period.

Although few projects have been completed for a period of time sufficient to determine the success of current techniques, Clewell (1989) predicts that projects which are carefully planned and executed can be successful. All of the types listed in Table D-3 should be possible to construct, with the possible exception of Cypress heads or strands in deep water. These can be established as shallow swamps instead. While Clewell states that all of the listed types should be possible to construct, work has primarily been done in the area of bottomland hardwoods and, secondarily, in cypress restoration (Clewell 1989). Some information does exist for the construction of White cedar swamps. As more information becomes available, this document will be supplemented.

D.2.3.4.1 Bottomland Hardwoods: Relatively substantial amounts of information have been researched and published on establishing this type of wetland. Newling (1990) discusses some organizations that research bottomland restoration (e.g., the Southern Hardwoods Research Laboratory at Stoneville, MS) and mentions guides for bottomland restoration (e.g., "Bottomland Hardwood Reforestation in the Lower Mississippi Valley" (Allen and Kennedy 1989).

Most bottomland hardwood reforestation involves establishing forest canopy, planting mostly species that do not volunteer easily, such as the heavy-seeded trees (Clewell 1989 and Newling 1990).

Clewell advises, however, that the undergrowth be considered: "otherwise, the project may become little more than a tree farm." Newling (1990) reports that most understory and light-seeded species will spread rapidly by natural means as long as a seed source is available for the site.

TABLE D-3

SOUTHEASTERN FORESTED WETLAND TYPES
(As described by Clewell 1989)

Type	Flood Duration	Location in Landscape	Characteristic Vegetation
Muck-swamp	Inundation prolonged and often deep	Fertile floodplains of larger alluvial streams of the Coastal Plain	*Taxodium distichum*, *Nyssa aquatica*
Cypress Heads or Strands	Inundation prolonged and often deep	Coastal Plain in peaty, acid isolated ponds or shallow, slowly moving streams draining bogs or peaty, acid swamps	*Taxodium ascendens*, *Nyssa biflora*
Bottomland Hardwoods	Seasonal flooding or where ground water maintains constantly high soil moisture	Fertile alluvial floodplains or valleys	Deciduous dicotyledonous trees (high variety)
Mesic Riverine Forest	Flood less frequently than bottomland hardwood areas, some not considered jurisdictional wetlands	Higher terraces and levees of floodplains and protected valley walls	Deciduous dicotyledonous trees (those that are less tolerant of frequent flooding), evergreen hardwoods, and some conifers
Bay Swamps	Varies	Peaty, acid headwater swamps of streams, colluvial swamps along tannic blackwater streams, seepages in some ravines, back swamps of larger floodplains ordinarily unaffected by river overflow, and isolated depressions within uplands	Broadleafed, coriaceous, evergreen trees; sometimes conifers
Peat Swamps	Varies	Areas of deep peat accumulation and banks of small, blackwater streams	*Cyrilla racemiflora*, *Ilex sp.*, *Lyonia lucida*, often conifers
White Cedar Swamps	Semipermanently, seasonally, or saturated (FWS Classification System; Laderman 1989)	Deep, peaty, acid, isolated, headwater swamps	*Chamaecyparis thyoides*
Wet Flats	Varies	Soils underlain by a plastic horizon that severely restricts filtration located in isolated wet depressions between streams	*Nyssa biflora*, *Taxodium ascendens*, *Pinus elliottii*, *Acer rubrum*

D.2.3.4.2 White Cedar Swamps: The range of Atlantic white cedar (*Chamaecyparis thyoides*) wetlands extends from Maine to Mississippi but is restricted to a narrow band that runs adjacent to the coast (Laderman 1989). Under Cowardin's classification system (1979) their water regime can include Semipermanently or Seasonally Flooded or Saturated conditions (Clewell 1989, Laderman 1989). These water regimes roughly describe the wetland types Permanently to Semipermanently, Regularly, or Seasonally Saturated or Inundated (Section D.2.1). It should be noted that, while some Atlantic white cedar swamps can be flooded long enough to be characterized as a Permanently to Semipermanently Flooded wetland, it is unlikely that they would be flooded for one hundred percent of the growing season because "mature trees are stressed by permanent inundation" (Laderman 1989). The intricate ecology of these wetlands depends, at least in part, on their hummocky composition. As Laderman (1989) explains, "Slightly elevated hummocks dominated by cedar are often interspersed with water-filled hollows in a repeating pattern that forms a readily identified functionally interrelated landscape."

Most of the attention focused on the regeneration of Atlantic white cedar is due to its commercial value. Harvest and management techniques proposed by Little (1950) remain the standard today (Laderman, personal communication). The method Little proposes involves clearcutting in strips so that adjacent stands of cedar remain as a seed source. Removal of slash and control of competing hardwoods, as well as browsing deer (Appendix I), are vital when using this method in order to allow white cedars to become established (Little 1950, Laderman 1989). These recommendations are important when considering Atlantic white cedar wetland replacement.

The actual restoration of Atlantic white cedar swamps has not yet been accomplished on scales large enough and for periods of time long enough to make conclusive statements on appropriate methods for success. Projects currently in progress involve creating hummocks in a variety of experimental arrangements and planting cedar cuttings (Laderman, personal communication). However, these projects are too new to provide any data for determining the best methods for success.

D.2.3.4.3 Cypress Heads or Strands: Cypress heads or strands are common in the southeastern portion of the country. Cypress heads (also known as ponds or domes) occur throughout Florida and in the Atlantic coastal zone, north into Virginia and in the Gulf coastal zone, and west into Louisiana (Ewel 1990). Their hydrology varies, but water levels usually fluctuate, dropping once or twice each year to expose the peat floor for a few weeks to several months (Ewel 1991). Depending on how long the peat floor is dry, they can be described as Permanently to Semipermanently or Regularly Saturated or Inundated wetland types.

Although some attempts have been made to restore the cypress swamps, no documented successful projects exist to guide future efforts (Ewel, personal communication). Some phosphate mine reclamation projects (e.g., Gilbert et al. 1981) have included the planting of bald cypress (*Taxodium distichum*); however, these projects have not been specific attempts at cypress swamp restoration. Some information from these efforts and from other cypress planting studies can serve as guidelines for future projects.

For example, a study on the regeneration of cypress (after logging) done by Gunderson (1984) revealed many critical factors in cypress revegetation. Hydrology is crucial because insufficient inundation causes high mortality, as will submersion of seedlings. Other studies (Dickson and Broyer 1972, Conner and Flynn 1989) showed that cypress grow best in soil that fluctuates between flooded and aerated conditions.

Conner and Flynn also found that protection from wildlife depredation is necessary for seedling survival. It is also important that seedlings are not outcompeted by hardwoods. If the expectation is to allow cypress to volunteer an area, a seed source must be both hydrologically connected and relatively close, since cypress seeds travel mainly by water but do not float for very long (Gunderson 1984). It is also essential for seeding that the water level drop: cypress seeds do not germinate when soils are flooded (Ewel 1990).

Cypress swamps are complex ecosystems which vary greatly from site to site. While the information above can be used to assist in the design of cypress replacement, local experts should be contacted to determine necessary elements for replacement efforts.

D.2.3.5 Playas

Playa lakes are located on the high plains of west Texas and into the corners of Kansas, Colorado, Oklahoma, and New Mexico. They are seasonally flooded wetlands which occur in shallow, circular basins (Rude 1991).

The process of creating a playa would take decades and is not currently practiced (Smith, personal communication). Restoration, however, is common for purposes of restoring waterfowl habitat. Many of the lakes have been impacted by the excavation of tailwater pits in their basins, which reduces evaporative loss and creates a more permanent water supply for irrigation and livestock (Gray and Bolen 1987). The construction of these pits reduces the littoral surface and prevents the growth of wetland vegetation.

The restoration of these basins can be accomplished simply by filling in the basins (Smith, personal communication). No planting is necessary because of the large seed bank available from vegetation that was present in the pre-impact, functioning wetland (Smith, personal communication; Gray and Bolen 1987).

Gray and Bolen (1987) also report that the construction of terraced edges to these pits can serve the purpose of concentrating water while also maintaining levels shallow enough and slopes flat enough to allow the growth of a number of types of wetland vegetation (e.g., submergents, emergents, moist soil plants). They did find, however, that vegetation from the terraced pits could not supply enough food to support waterfowl totally; rather, it would supplement their diet.

D.2.3.6 Nontidal, Freshwater Submerged Aquatic Beds

The creation of submerged aquatic beds via the planting of submerged aquatic vegetation (SAV) in ponds or freshwater streams involves many of the same precautions as the planting of seagrasses in tidal areas (Section D.1.3.2). SAV beds exist throughout the country. Species distribution is limited by climate, water turbidity, water movement, and sometimes by nutrients and chemicals in the water. Some species are well adapted to withstand considerable current or wave action, while others prefer slowly moving water. Various species have different depth preferences. Table D-4 provides examples of the various species requirements and tolerances.

D.2.3.7 Sedge Meadows

Sedge meadows are usually located in the north central part of the United States. They can be regularly or seasonally saturated or inundated wetlands, with water levels fluctuating throughout the growing season. Sedge meadows can be isolated depressions surrounded by a gradual grade toward upland. In this gradual grade, a transition area of wet meadow and/or wet prairie may be present. Sedge meadows can also be transition areas themselves between marsh and wet meadow (which grades up toward upland prairies).

TABLE D-4

SUBMERGED AQUATIC VEGETATION REQUIREMENTS AND TOLERANCES*

Species	Water Quality	Water Movement	Substrate	Depth in Feet
Ceratophylum demersum (Coontail)	Fresh, soft or hard; tolerates turbidity / shade	Slow-moving streams and ponds	Not dependent (unrooted)	2 to 5
Elodea canadensis (Elodea)	Hard, clear fresh	Quiet ponds, bays, sloughs or sluggish streams and lakes	Mud or sandy loam	1 to 10
Potamogeton nodosus (Longleaf pond plant)	Fresh water	Lakes, streams, ponds	Muddy or sandy	1 to 6
Potamogeton pectinatus (Sago pond weed)	Hard, clear, fresh, marl, alkali, or brackish	Quiet or moving; stands considerable current or waves	Silt-mud	1.5 to 8
Potamogeton perfoliatus (Redhead grass)	Fresh, moderately brackish, or alkaline	Quiet with slow moving currents	Mud or sandy	1 to 6
Vallisneria spiralis (Wild celery)	Hard fresh or slightly brackish; fairly clear	Withstands waves or currents	Mud, sandy, or coarse silt	1.5 to 8

* Summarized from Lemberger 1981 and Hurley 1990.
Refer to Vegetation Tables in Appendix G for more information on SAV

Common practices for the creation of sedge meadows, as explained by Gillespie (personal communication), currently involve planting seedlings of a quickly establishing sedge (such as *Carex stricta, C. lacustris, C. rostrata, or C. atherodes*, the last two species for deeper water) on approximately a one-foot square grid. In some situations, it is important to use seedlings with well-developed root systems to prevent seedling washouts (Kerans 1990, and Gillespie, personal communication). Once this primary vegetation becomes established and hummocks or tussocks have developed with depressions between them, the area begins to resemble a sedge meadow community. This can take one to four years, depending on species used and site conditions. It may then be necessary to seed other species which would begin the development of a more diverse community (e.g., *Calamagrostis canadensis* and *Asclepias incarnata*). A variety of species will volunteer in this situation, but this process may be longer than the time period desired to establish a complete community.

Wet meadows are usually adjacent to the sedge meadow community and have a slightly dryer water regime. Establishing these wetlands usually involves techniques similar to those for sedge meadows; however, the vegetation planted is different. Primary pioneer species in this ecosystem (as suggested by JoAnn Gillespie) include *Carex lanuginosa, C. hystricina, C. stipida,* and *C. cephalophora*. A few species that can be seeded after the *Carex* become established are *Eupatorium perfoliatum, E. maculatum, Chelone glabra, Asclepias incarnata,* and *Verbena hastata*. The examples given are for southern and central Wisconsin where sedge meadows and wet meadows are common. Each *Carex* species is adapted to a specific range of conditions (geographic, hydrologic, etc.). It is best to consult experts to determine which is best for planting in specific site conditions.

D.3 REFERENCES CITED

Allen, J.A. and H.E. Kennedy, Jr. 1989. Bottomland Hardwood Reforestation in the Lower Mississippi Valley. U.S. Fish and Wildlife Service, Slidell, Louisiana and Southern Forest Experiment Station, Stoneville, Mississippi. 28 pp.

Citron-Molero, G. 1992. Restoring Mangrove Systems. In J. W. Thayer (Ed.), Restoring the Nation's Marine Environment College Park, Maryland: Maryland Sea Grant College, University of Maryland.

Clausen, J.C. and K.N. Brooks. 1980. The Water Resources of Peatlands, A Literature Review: Report to Minnesota Department of Natural Resources. Department of Forest Resources, College of Forestry, University of Minnesota. 143 pp.

Clewell, A.F. 1989. Creation and restoration of forested wetland vegetation in the southeastern United States, pp. 199-237. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Vol. I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Conner, W.H. and K. Flynn. 1989. Growth and survival of bald cypress (Taxodium distichum [L.] Rich.) planted across a flooding gradient in a Louisiana bottomland forest. Wetlands 9(2):207-217.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. FWS/OBS-79/31. U.S. Fish and Wildlife Service, Washington, DC. 131 pp.

Crewz, D.W. and R.R. Lewis III. 1991. An Evaluation of Historical Attempts To Establish Emergent Vegetation in Marine Wetlands in Florida. Technical Paper No. 60. Florida Sea Grant College.

DeBell D.S. and A.W. Naylor. 1972. Some factors affecting germination of swamp tupelo seeds. Ecology 53(3):504-506.

Dickson, R.E., and T.C. Broyer. 1971. Effects of aeration, water supply, and nitrogen source on growth and development of tupelo gum and bald cypress. Ecology 53(4):626-634.

Ewel, K.C. 1990. Multiple demand on wetlands: Florida cypress swamps can serve as a case study. BioScience 40(9):660-666.

Ewel, K.C. 1991. Swamps, pp. 281-323. In R.L. Myers and J.J. Ewel (Eds.), Ecosystems of Florida. University of Central Florida Press, Orlando, Florida.

Ferren, W.R., Jr. and E.M. Gevirtz. 1990. Restoration and creation of vernal pools: cookbook recipes or complex science? pp. 147-178. In D.H. Ikeda and R.A. Schlising (Eds.), Vernal Pool Plants-Their Habitat and Biology. Studies from the Herbarium No. 8. California State University, Chico.

Ferren, W.R., Jr. and D.A. Pritchett. 1988. Enhancement, Restoration, and Creation of Vernal Pools at Del Sol Open Space and Vernal Pool Reserve, Santa Barbara County, California. Environmental Report No. 13. University of California, Santa Barbara. 168 pp.

Fonseca, M.S. 1989. Regional analysis of the creation and restoration of seagrass systems, pp. 175-198. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science Vol I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Fonseca, M.S. 1992. Restoring Seagrass Systems in the United States. In G. W. Thayer (Ed.), Restoring the Nation's Marine Environment. College Park, Maryland: Maryland Sea Grant College, University of Maryland.

Galatawitsch, S. M. And A. G. Van der Valk. 1994. Restoring Prairie Wetlands: An Ecological Approach. Ames, Iowa: Iowa State University Press.

Gilbert, T., T. King, and B. Barnett. 1981. An Assessment of Wetland Habitat Establishment at a Central Florida Phosphate Mine Site. FWS/OBS-81/38. U.S. Fish and Wildlife Service, Washington, D.C.

Gosselink, J.G. 1984. The Ecology of Delta Marshes of Coastal Louisiana: A Community Profile. FWS/OBS-84/09. U.S. Fish and Wildlife Service, Washington, DC. 134 pp.

Gray, P.N. and E.G. Bolen. 1987. Seed reserves in the tailwater pits of playa lakes in relation to waterfowl management. Wetlands 7:11-23.

Gunderson, L.H. 1984. Regeneration of cypress in logged and burned strands of Corkscrew Swamp Sanctuary, Florida. In K.C. Ewel and H.T. Odum (Eds.), Cypress Swamps. University Presses of Florida, Gainesville, Florida.

Hook, D.D. 1988. Criteria for creating and restoring forested wetlands in the southern United States, pp. 51-60. In J. Zelzny and J.S. Feierabend (Eds.), Proceedings of Wetlands: Increasing Our Wetland Resources. National Wildlife Federation, Washington, D.C.

Hurley, L.M. 1990. Field Guide to the Submerged Aquatic Vegetation of Chesapeake Bay. U.S. Fish and Wildlife Service, Annapolis, Maryland. 51 pp.

Kantrud, H.A., G.L. Krapu, and G.A. Swanson. 1989. Prairie Basin Wetlands of the Dakotas: A Community Profile. Biological Report 85(7.28). U.S. Fish and Wildlife Service, Washington, DC. 116 pp.

Kerans, K. 1990. The restoration business: Country Wetlands Nursery Ltd. Restoration & Management Notes 8(1):29-30.

Kirkman, H. 1992. Large-scale Restoration of Seagrass Meadows. In G. W. Thayer (Ed.), Restoring the Nation's Marine Environment. College Park, Maryland: Maryland Sea Grant College, University of Maryland.

Klimas, C.V. 1988. River regulation effects on floodplain hydrology and ecology, pp. 40-49. In D.D. Hook, W.H. McKee, Jr., H.K. Smith, J. Gregory, V.G. Burrell, Jr., M.R. DeVoe, R.E. Sojka, S. Gilbert, R. Banks, L.H. Stolzy, C. Brooks, T.D. Matthews, and T.H. Shear (Eds.), The Ecology and Management of Wetlands Volume 1: Ecology of Wetlands. Timber Press, Portland, Oregon.

Laderman, A.D. 1989. The Ecology of Atlantic White Cedar Wetlands: A Community Profile. Biological Report 85(7.21). U.S. Fish and Wildlife Service, Washington, DC. 114 pp.

Larson, J.S. 1988. Wetland creation and restoration: an outline of the scientific perspective. In J. Zelazny and J.S. Feierabend (Eds.), Proceedings of Wetlands: Increasing Our Wetland Resources. National Wildlife Federation, Washington, DC.

Larson, J.S., J.S. Bedinger, C.F. Bryan, S. Brown, R.T. Huffman, E.L. Miller, D.G. Rhodes, and B. Arville Touchet. 1981. Transition from wetlands to uplands in southeastern bottomland hardwood forests, pp. 225-273. In J.R. Clark and J. Benforado (Eds.), Wetlands of Bottomland Hardwood Forests: Proceedings of a Workshop on Bottomland Hardwood Forest Wetlands of the Southeastern United States. Elsevier Scientific Publishing Company, Amsterdam.

Lemberger, J. 1981. Wildlife Nurseries Plant Catalog (What Brings Them In). Wildlife Nurseries, Oshkosh, Wisconsin.

Lewis, R.R. III. 1987. The restoration and creation of seagrass meadows in the southeast United States. In M.J. Durako, R.C. Phillips, and R.R. Lewis (Eds.), Proceedings of the Symposium on Subtropical-Tropical Seagrasses of the Southeastern U.S. Florida Department of Natural Resources, St. Petersburg, Florida.

Lewis, R.R. III. 1989. Creation and restoration of coastal plain wetlands in Florida, pp. 73-101. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science. Vol. I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Little, S., Jr. 1950. Ecology and Silviculture of White Cedar and Associated Hardwoods in Southern New Jersey. Bulletin No. 56. Yale University: School of Forestry, New Haven, Connecticut.

Newling, C.J. 1990. Restoration of bottomland hardwood forests in the lower Mississippi Valley. Restoration & Management Notes 8(1):23-28.

Nilsson, H.D., N.C. Famous, and M.P. Spencer. 1990. Harvested Peatland Reclamation: Harvesting Impacts, Case Studies and Reclamation Options (Draft). Down East Peat L.P., Cherryfield, Maine.

Odum, W.E. and J.K. Hoover. 1988. A Comparison of Vascular Plant Communities in Tidal Freshwater and Saltwater Marshes, pp. 526-534. In D.D. Hook, W.H. McKee, Jr., H.K. Smith, J. Gregory, V.G. Burrell, Jr., M.R. DeVoe, R.E. Sojka, S. Gilbert, R. Banks, L.H. Stolzy, C. Brooks, T.D. Matthews, and T.H. Shear (Eds.), The Ecology and Management of Wetlands Volume 1: Ecology of Wetlands. Timber Press, Portland, Oregon.

Odum, W.E., C.C. McIvor, and T.J. Smith III. 1982. The Ecology of the Mangroves of South Florida: A Community Profile. FWS/OBS-81/24. U.S. Fish and Wildlife Service, Washington, DC. 144 pp.

Patrick, W.H., Jr. 1981. Bottomland soils, pp. 177-185. In J.R. Clark and J. Benforado (Eds.), Wetlands of Bottomland Hardwood Forests: Proceedings of a Workshop on Bottomland Hardwood Forest Wetlands of the Southeastern United States. Elsevier Scientific Publishing Company, New York.

Rude, K. 1991. The playas. Ducks Unlimited March/April.

Stewart, R.E. and H.A. Kantrud. 1971. Classification of Natural Ponds and Lakes in the Glaciated Prairie Region. Resource Publication 92. Bureau of Sport Fisheries and Wildlife, Washington, DC. 57 pp.

Teas, H.J. 1977. Ecology and restoration of mangrove shorelines in Florida. Environmental Conservation 4(1):51-58.

Twaroski, C.J. and V. Kurmis. 1982. Revegetation of Mined Peatlands: II. Field Testing of Grasses and Site Treatments. University of Minnesota, Department of Forest Resources, Minnesota. 107 pp.

U.S. Army Corps of Engineers. 1987. Corps of Engineers Wetlands Delineations Manual. Technical Report Y-87-1. U.S. Army Corps of Engineers, Washington, DC.

Zedler, P.H. 1987. The Ecology of Southern California Vernal Pools: A Community Profile. Biological Report 85(7.11). U.S. Fish and Wildlife Service, Washington, DC. 136 pp.

Zedler, P.H. 1989. California's vernal pools. National Wetlands Newsletter May-June:2-5.

Zieman, J.C. and R.T. Zieman. 1989. The Ecology of the Seagrass Meadows of the West Coast of Florida: A Community Profile. Biological Report 85(7.25). U.S. Fish and Wildlife Service, Washington, DC. 155 pp.

APPENDIX E
HYDROLOGY

E.1 INTRODUCTION

Hydrology is the science that relates to the occurrence, properties, and movement of water on the earth. The domain of hydrology is extremely broad. It includes water found in the oceans, lakes, and rivers of the world, as well as in upland areas, above and below ground, and in the atmosphere. Within this domain, wetlands occur at the boundaries between aquatic and terrestrial environments, between groundwater and surface water flow systems. Because of this intermediate or boundary position, wetlands are sensitive and responsive to changes which affect either aquatic or terrestrial conditions. For example, a long-term rise in surface water level may change the location, extent, and configuration of adjacent wetlands; hydrologic changes in an upland area may alter the physical features and water quality of downstream receiving wetlands. In this sense, wetlands are the victims of hydrologic circumstance. They may be regarded primarily as a "dependent variable" within the hydrologic cycle, occurring at the edges which separate land from water bodies and responding to hydrologic changes which influence them.

The above characterization is actually somewhat oversimplified. In reality, wetlands not only respond to hydrologic conditions, but also they interact with and exert some degree of control over them in certain situations. For example, peat-building wetlands reduce the flow of groundwater through their beds; wetland vegetation may affect transpiration and influence the rate and pattern of surface water flowing through the wetland; and some animals such as beavers can significantly alter the location and extent of wetland areas. However, despite the occasional local importance of these physical and biotic controls, the predominant relationship between hydrology and wetlands is one of cause and effect.

According to Mitsch and Gosselink (1986), "hydrology is probably the single most important determinant for the establishment and maintenance of specific types of wetlands and wetland processes." Despite its known importance, however, wetland hydrology is poorly understood. There are many reasons for this, among which are the following:

- **The subject is inherently complex.** The study of any physical system is usually more complex at the system's boundaries. Hydrologically speaking, wetlands represent such boundaries. Their study requires a thorough understanding of terrestrial and aquatic environments, as well as groundwater and surface water flow principles.

- **Historically, little importance has been attached to the study of wetland hydrology or, for that matter, to wetlands themselves.** Compared with hydrologic applications such as flood flow forecasting, for which the perceived societal need has always been great, the state of the science regarding wetland hydrology is poorly advanced.

- **Academically, the disciplines involved in wetland hydrology are diverse and often fragmented.** Traditional engineering curricula address surface or groundwater hydrology (seldom both) from an applied, quantitative standpoint, but they rarely include the geologic and geomorphologic background which is a prerequisite for understanding the role of wetlands within the overall hydrologic landscape. Geologists and geomorphologists, on the other hand, are seldom trained or versed in the quantitative aspects of hydrology which are necessary for the assessment and design of wetland replacement projects.

For the above reasons, we find ourselves in somewhat of a dilemma regarding the study and application of wetland hydrologic concepts. On the one hand, hydrology is known to have a dominant influence on the occurrence and behavior of wetlands. On the other, the science of wetland hydrology is poorly understood and still in its relative infancy. The overriding reality, however, is that wetland replacement projects, spurred by a growing awareness of wetland values and accompanying regulatory controls, are ongoing. Projects are unable to await further research experience, and evaluation, which are needed to advance wetland hydrology to a more mature scientific level. The most practical response to this dilemma appears to be an application of best available hydrologic knowledge in the wetland replacement process, together with a realistic recognition that further research and monitoring of actual projects are necessary before the hydrologic design of replacement wetlands can be performed with confidence or standardized to a reasonable degree.

This appendix represents an attempt to synthesize those aspects of the broad science of hydrology which relates directly to the wetland replacement process. As part of this effort, some preliminary guidelines have been offered for the hydrologic evaluation procedures which are integral to this process. It must be emphasized, however, that these guidelines are typically quite general and in all cases unvalidated. (We believe that meaningful hydrologic validation of actual replacement wetlands is presently impossible, except in the fairly narrow sense described subsequently in this appendix.) Given the present state of the science, it is anticipated that the hydrologic design of replacement wetlands will, for some period of time, involve a significant degree of trial and error. However, we believe that guidelines such as those presented herein, expanded and modified on the basis of further research and actual project experience, will eventually lead to a more standard and predictable process for the hydrologic design of replacement wetlands.

The remainder of this appendix is organized as follows:

- Section E.2 includes a summary description of those basic hydrologic concepts whose understanding is important for the more specific subject of wetland hydrology.
- Section E.3 addresses wetland hydrology, with an emphasis upon those applied aspects which affect the siting and design of replacement wetlands; this section concludes with the recommendation of a preliminary and general framework for the design of replacement wetlands.
- Section E.4 lists the references cited in this appendix.

E.2 BASIC HYDROLOGIC CONCEPTS

This section deals with basic hydrologic concepts which are fundamental to an understanding of wetland hydrology. Because the science of hydrology is so broad, the scope and depth of the following presentation has been intentionally limited to address only those issues which are most directly related to wetland hydrologic processes. The treatment is, therefore, neither comprehensive nor detailed. For an in-depth review of hydrology, the reader is referred to any of the numerous texts on this subject, a number of which are cited within the following discussion.

E.2.1 THE HYDROLOGIC CYCLE

The hydrologic cycle refers to the processes involved in the transfer of water from the sea to the land and back to the sea again. Water within the hydrologic cycle occupies three separate zones:

- The hydrosphere—the permanent surface water bodies which occupy approximately 70 percent of the earth's surface area.

- The lithosphere—the consolidated and unconsolidated earth materials which underlie and abut the hydrosphere.
- The atmosphere—the air which overlies the hydrosphere and lithosphere.

As its name implies, the hydrologic cycle involves a continuous state of water motion and transfer among these zones.

Figure E-1 provides a simplified schematic representation of the hydrologic cycle, indicating its principal components and their relationship to one another. The following sections address these components from both a descriptive and quantitative standpoint. Before proceeding with this discussion, however, it is necessary to define several key terms related to the hydrologic cycle. It should be noted that, throughout the hydrologic literature, there is considerable inconsistency in the definition and usage of terms. The terminology below is commonly, though not universally, applied in the manner presented.

- **Precipitation** refers to all water which falls from the earth's atmosphere to its surface in liquid (rainfall) or frozen (snow, hail, sleet) form.
- **Evaporation** is the transformation of water from the liquid to the vapor state.
- **Transpiration** is the transfer of water from plants to the atmosphere.
- **Evapotranspiration** is the transfer of water to the atmosphere by the combined, and often practically inseparable, processes of evaporation and transpiration.
- **Total runoff** is that fraction of precipitation which reaches a surface water body (stream, lake, ocean) at the outlet of a drainage basin or watershed. It includes surface runoff, interflow, and groundwater flow.
- **Surface runoff** is that portion of total runoff which reaches the basin outlet by flow across the surface of the ground and through stream channels.
- **Interflow** is that portion of total runoff which flows underground, above the permanent water table, and toward a stream channel or basin outlet.
- **Groundwater flow** is that portion of total runoff which percolates through the ground, reaching the permanent water table and flowing underground to discharge eventually into a stream channel or other surface water body.

As indicated by Figure E-1, water occurring in the earth's oceans is transferred to the atmosphere by the process of evaporation and returned by the processes of direct precipitation on the ocean surface plus runoff derived from precipitation occurring over land masses. The average annual precipitation across the United States is approximately 30 inches. Of this, approximately 21.5 inches is evapotranspired back to the atmosphere and 8.5 inches returns to the oceans as runoff-derived streamflow (Linsley and Franzini 1972). In some texts, evaporation and transpiration are referred to as "losses." While this may be accurate on a limited scale or for a particular application, in the truest sense, there are no water "losses" within the hydrologic cycle, only transfers from one medium or zone to another.

The hydrologic cycle is actually far more complex than indicated by the above discussion and the schematic diagram in Figure E-1. Its components are intricately related and interdependent. For example, soil moisture depends upon infiltration, which is in turn influenced by the percentage of precipitation evapotranspired back to the atmosphere; evapotranspiration, on the other hand, is a function of soil moisture during the growing season. Despite such known complexities, however, the simplified model indicated by Figure E-1 is a useful tool for describing and quantifying the principal components of the hydrologic cycle.

E.2.2 PRECIPITATION

Precipitation is caused by a cooling of the earth's atmosphere so that moisture, which is always present in air, condenses as rainfall or snow/sleet/hail. Atmospheric cooling occurs when warm air is lifted to higher and cooler altitudes, where lower pressures allow it to expand and consequently cool down. There are two principle mechanisms responsible for the lifting of warm air masses which ultimately produce precipitation:

- Orographic barriers such as hills or mountains which force blowing air upward and over them; and
- Unequal heating of the earth's atmosphere and surface which produces warm and cold fronts (convective systems) at whose interface the lighter warm air is forced to rise up and over the heavier cold air. A detailed discussion of the physics and hydrodynamics of rainfall is presented in Gilman (1964).

Precipitation is measured as depth falling on a level surface. The common unit of measurement in the United States is inches. The standard rainfall gage used by the United States National Weather Service consists of a copper collector, 8 inches in diameter, which funnels into a 2.53-inch-diameter measuring tube encased within an overflow can. (The size ratio between collector and measuring tube is set so that 0.1 inches of rainfall falling on the collector will fill the tube to a depth of 1.0 inches.) When snow is anticipated, the collector and tube are removed, snowfall is collected directly in the overflow can, and the snow is melted and poured into the tube for measurement. Precipitation gages may be either manual or automatically recording. For a further discussion of the various types of precipitation gages, the reader is referred to Linsley, Kohler, and Paulhus (1982).

In hydrologic studies, it is frequently necessary to determine the average precipitation for some specified time interval which occurs over a watershed or sub-watershed area. Most often, this is done by combining information from a number of gages comprising a precipitation gage network. The simplest precipitation averaging method involves simply calculating the arithmetic mean of the different gage measurements. Although this may be satisfactory when considering very small drainage areas, it can produce large errors for the typically non-uniform precipitation pattern which occurs over larger watersheds, especially if the precipitation gages are unevenly distributed throughout the watershed. A generally more satisfactory method for computing average precipitation from a precipitation gage network is to weight the precipitation data from the different gages within the network. The two most common weighting methods are the Thiessen Polygon and Isohyetal methods, as described below:

- **Thiessen Polygon method:** Using this method, perpendicular bisectors are constructed between each of the precipitation gages within the drainage network, as indicated by Figure E-2. The areas of the resulting polygons are calculated and assigned to the gage stations centered within each polygon. The weight of each gage, used in the averaging process, is equal to the ratio of its corresponding polygon area to the total watershed area. Example calculations are included on Figure E-2.
- **Isohyetal method:** Where the variability of precipitation within a watershed has a spatial trend (e.g., increasing precipitation at higher elevations), the Isohyetal method is more accurate than the Thiessen Polygon method. Isohyets, or contours of equal precipitation, are constructed on the basis of gage precipitation data, and the areas between contour lines are calculated (typically using a polar

planimeter). The weighted average precipitation over the watershed is calculated as shown by the example on Figure E-3.

Although, on a global basis, precipitation is related to and dependent upon other components of the hydrologic cycle, it may be regarded as an essentially independent variable when evaluating the hydrology of individual watersheds, or watershed features such as wetlands. Approximately 90 percent of the moisture available for continental precipitation is contributed by evaporation from ocean surfaces (Linsley et al. 1982). Watershed precipitation is, therefore, essentially independent of the other two principal components of a watershed's hydrologic budget—evapotranspiration and runoff. It controls the amount of water available for these other components and thereby ultimately controls the flow rates and water levels occurring above and below ground throughout the watershed. This makes an understanding of the occurrence and variability of precipitation crucial to almost all hydrologic studies.

Precipitation varies in both space and time. Its occurrence and distribution are stochastic, rather than deterministic. This means that precipitation data must be expressed on the basis of probability, or frequency of occurrence. For example, if the annual probability that a 24-hour rainfall at a location will exceed 3 inches is 0.10, this means that there is a 10 percent chance that a rainfall of such magnitude will be equaled in any given year, or that such a rainfall will occur, on average, once in every 10 years. In this case, 10 years is referred to as the return period, and is equal to the inverse of the probability of occurrence. Although a more detailed discussion of probability concepts is beyond the scope of this discussion, it is addressed in depth in *Hydrologic Frequency Analysis* (U.S. Army Corps of Engineers 1975). It is important to note that, because future precipitation can only be estimated on the basis of probability, and because precipitation ultimately controls the occurrence and fluctuation of water levels within a watershed or a wetland, these water levels are also stochastic by nature. It follows logically that there is, therefore, a considerable, and unavoidable, degree of uncertainty in any hydrologic analysis or design.

The following discussion addresses, in very general terms, the types and degrees of variation which can be expected when evaluating the occurrence and distribution of precipitation within a watershed or wetland drainage basin.

- **Precipitation varies geographically.** Figure E-4 indicates the distribution of mean annual precipitation across the United States. Nationwide, the average annual precipitation is approximately 30 inches. However, this varies greatly, from a few inches per year in the southwest United States to well over one hundred inches per year in parts of the northwest. In general, precipitation increases with decreasing latitude, since atmospheric moisture is greater with warmer temperatures. Precipitation also increases with proximity to a major moisture source and is therefore generally greater in coastal areas. The effect of mountains on orographic precipitation is also evident in the western United States, with large bands of high precipitation occurring on the windward side of major mountain ranges.

- **Precipitation varies locally.** Over short periods of time, such as during a storm, the stochastic nature of precipitation produces very large variations over relatively short distances. These local variations tend to "even out" over the course of a season or year, unless they are caused or contributed to by physical features such as local upland areas.

- **Storm precipitation intensity decreases with increasing storm duration.** When considering individual storms of a given frequency, the intensity of precipitation (i.e., the depth of precipitation per unit time) always decreases with increasing storm duration. Because this subject is important for the design of storm drainage and stormwater management systems, much statistical information has been published concerning it. In fact, rainfall intensity-duration-frequency curves have been established for almost all urban areas of the United States, to be used for the design of such systems. In addition, the National Weather Service has published nationwide rainfall intensity-frequency-duration maps for durations ranging from 30 minutes to 24 hours, and return periods ranging from 1 to 100 years (United States Weather Bureau 1961). For wetland analysis and design, we are usually less concerned with large storm events than with long-term water supply potential. Nevertheless, storm-related precipitation is of importance also, especially for the design of spillway or other outlet structures which must provide ample passage of water from the wetland during high runoff conditions.

- **Precipitation varies seasonally.** Figure E-5 indicates the significant variation in seasonal precipitation pattern which occurs in different climatic regions of the United States. On the west coast, precipitation is lowest during the summer months. Conversely, throughout the Great Plains, precipitation is typically highest during the summer. On the east coast, precipitation tends to be fairly evenly distributed throughout the year.

- **Precipitation varies annually.** In addition to its seasonal variation, precipitation varies considerably from year to year. Although numerous studies have been undertaken to evaluate the possibility of long-term precipitation cycles, the results are inconclusive. However, although unpredictable, the variable nature of annual precipitation in all regions is well known and is an important factor in the design of water supply systems and wetland restoration projects. Figure E-6 indicates the percentage deviation from normal annual precipitation which occurs across the United States. As can be seen from this figure, there is a 25 percent chance that precipitation in any year will be at least 50 percent above or below its long-term average value throughout almost all of the central and western United States. Although the variation in the eastern states is somewhat less, it is still substantial. Figure E-7 provides another perspective on this annual variation in precipitation. It demonstrates that the ratio of wettest to driest years across the United States varies from approximately 1.5 in the northeast to 3.5 in the southwest. The important conclusion to be drawn from these statistics is that precipitation, which ultimately controls the supply and levels of water available for non-tidal wetland restoration projects, is highly variable and cannot be expected to occur in a consistent or predictable manner from year to year.

The primary source of precipitation data in the United States is the National Weather Service (NWS), a division of the National Oceanic and Atmospheric Administration (NOAA). The NWS collects daily precipitation and other climatological data at over 20,000 stations throughout the fifty States and Puerto Rico. This information is available through the National Climatic Data Center in Asheville, North Carolina (Telephone: 704-259-0682), as well as through six Regional National Weather Service offices. Monthly *Climatological Data* reports are published by state and are available in most large public and university libraries. These monthly reports include daily values for precipitation, temperature and other climatological data at each of the measurement stations within the state.

PRIMARY SOURCE OF PRECIPITATION DATA IN THE UNITED STATES

The primary source of precipitation data in the United States is the National Weather Service, a division of NOAA. The National Weather Service collects data at over 20,000 stations throughout the U.S. and Puerto Rico. This information is available through the National Climatic Data Center at 704/259-0682.

E.2.3 EVAPORATION AND TRANSPIRATION

More than two-thirds of the water which falls each year on the United States as precipitation is returned to the atmosphere by the processes of evaporation and transpiration. Despite their quantitative importance, these processes are difficult to measure, and are often either roughly approximated or indirectly calculated as the residual term in detailed water balance studies (Section E.2.5). This section briefly describes the physical processes of evaporation and transpiration, indicates how they are measured, and identifies available sources of information concerning their magnitude and variability.

E.2.3.1 Evaporation

According to Dalton's Law (Dalton 1802), the rate of evaporation from a free water surface is proportional to the difference between the vapor pressure at the water surface and that in the air overlying the water surface. This law is expressed mathematically as: $E = C\,(ew - ea)$ [2.1]

where, E = evaporation rate
C = coefficient (function)
ew = vapor pressure at water surface
ea = vapor pressure in overlying air

Despite the apparent simplicity of Dalton's Law, using it to quantify evaporation from a free water surface is actually quite difficult. Numerous experimental studies have been performed for this purpose. One major difficulty in applying Dalton's Law is that the process is actually a complex function of numerous variables, some of which are interdependent. For example, evaporation from a free water surface is affected by:

- **Wind**, which tends to remove water molecules in the overlying air, reducing its vapor pressure and thereby increasing the rate of evaporation;
- **Dissolved solids**, which tend to reduce the vapor pressure of the water body and thereby decrease the rate of evaporation;
- **Differential temperatures**, which can increase or decrease the temperature of water relative to overlying air, thereby changing the vapor pressure of water relative to air and the rate of evaporation;
- **Atmospheric pressure**, for which a change would be accompanied by one in air vapor pressure and an increase in evaporation rate, provided that all other climatic factors remained unchanged.

Veihmeyer (1964) and Linsley et al. (1982) provide detailed descriptions of the numerous methods and equations which have been used to predict evaporation from free water surfaces. These methods, theoretical and empirical, include the use of water balance, energy balance, and energy transfer approaches. Although such methods have been successfully used to predict evaporation from existing lakes and reservoirs, they typically require the collection of extensive data, which are necessary to establish empirical coefficients for a specific site. This makes the application of such methods generally expensive, time-consuming, and somewhat site-specific.

A less accurate, but more practical and more widely used, method for predicting free water surface evaporation involves direct measurement using evaporation pans located either at or in the vicinity of an existing or proposed project site. The U.S. National Weather Service uses a standardized "Class A" evaporation pan, which consists of an unpainted, galvanized iron cylinder, 4 feet in diameter and 10 inches deep, raised approximately 6 inches above the ground on a wooden frame to let air circulate underneath. The water surface within the pan is maintained at a depth of 2 to 3 inches and measured daily. Evaporation is calculated as the difference between water levels, corrected for any precipitation falling during the measurement period. There are other types of evaporation pans, including some which are sunken into the ground surface and some which are floated on the surface of a lake or reservoir.

The purpose of these variations is to simulate more closely the natural environment by reducing the effects of non-representative wind patterns and/or heat transfer relationships within the pans. Even with such modifications, however, it is impossible to design an evaporation pan which perfectly simulates the aerodynamic and thermodynamic properties of a natural water body. It has been found that, in almost all cases, annual lake evaporation (Er) is significantly less than annual pan evaporation (Ep). Although there is considerable variation in the so-called "pan coefficient" (i.e., the Er/Ep ratio), studies have shown that an average value of approximately 0.7 applies fairly well for Class A evaporation pans (Linsley and Franzini 1972). This value of pan coefficient is typically used in hydrologic analyses to convert measured pan evaporation to free water surface evaporation. Although this standard coefficient value of 0.7 is relatively reliable in general, Winter (1981) suggests that it should be used only for annual data and not for monthly water balance analyses. Figure E-8 shows average annual lake evaporation across the United States, determined by converting National Weather Service pan evaporation data to lake evaporation by use of the pan coefficient of 0.7.

The determination of evaporation from soil surfaces is similar to, but more complex than, the determination of free water surface evaporation. Water evaporating from soil is generally influenced by the same factors as those influencing free water evaporation, though it must also overcome the additional attraction between soil particles and water. In addition, evaporation from soil surfaces is limited by the availability of moisture within the soil. Unless soil moisture is available, the soil will dry rapidly and evaporation will cease. Because most soil surfaces are vegetated to some degree, the subject of soil evaporation is typically addressed in conjunction with transpiration.

TABLE E-1

GEOGRAPHIC AND SEASONAL VARIATION OF CLASS A PAN EVAPORATION
(after Linsley and Franzini 1972)

Month	Newark, Calif.	W. Palm Beach, Fla.	Vicks-burg, Miss.	Seattle, Wash.	Norris, Tenn.	Ithaca, N.Y.	Lincoln, Nebr.	Hoaeae, Hawaii	Bartlett Dam, Ariz.
January	1.36	3.42	1.67	†	1.01	†	†	3.56	4.09
February	1.90	3.73	2.10	0.89	1.32	†	†	3.85	4.50
March	3.42	4.99	3.79	1.76	2.65	†	†	4.73	7.10
April	5.05	6.11	4.96	2.91	4.08	†	5.73	5.44	10.43
May	7.19	6.54	5.95	4.40	5.52	4.29	7.00	5.99	14.55
June	8.27	6.20	6.60	4.77	6.15	5.16	8.58	6.37	17.03
July	8.75	6.88	7.13	6.28	5.88	5.87	10.54	7.00	17.23
August	7.73	6.37	6.68	4.97	5.24	4.94	8.78	7.00	14.50
September	6.60	5.18	5.06	3.25	4.33	3.35	6.94	5.88	12.70
October	4.32	4.87	3.91	1.55	2.96	2.14	4.63	5.28	9.25
November	2.35	3.60	2.34	0.65	1.61	†	†	3.88	6.06
December	1.26	2.98	1.42	0.53	0.94	†	†	3.57	4.19
Year	58.20	60.87	51.61	...	41.69	...	...	62.55	121.63

Mean Monthly and Annual Evaporation from Free Water Surface, *U.S. Weather Bur. Tech. Paper* 13, 1950.
† Pan inoperative because of ice.

E.2.3.2 Transpiration

Transpiration is essentially the loss of water from plant leaves. The process is very similar to, and influenced by the same factors as, evaporation. These include temperature, humidity, wind, and solar radiation. Transpiration from vegetated soil surfaces is also, however, strongly influenced and limited by available soil moisture. Although there are a number of methods available for the measurement of transpiration alone (Veihmeyer 1964), in practice the water "loss" to the atmosphere from vegetated soil and water surfaces is almost always evaluated as combined evapotranspiration.

E.2.3.3 Evapotranspiration

Evapotranspiration, which is sometimes referred to as total evaporation or consumptive use, refers to the evaporation from all surfaces (free water, soil, vegetation), plus transpiration. Referring to Figure E-1, evapotranspiration is equal to the difference between precipitation and total runoff. A variety of methods have been used to estimate evapotranspiration, including:

- **Water balance methods:** Because evapotranspiration is equal to the difference between precipitation and total runoff, it can be determined by measurement and subtraction of these two terms. Such water balance methods have been applied at different scales, from entire watersheds to field plots. The problem with such methods is that evapotranspiration, calculated as the residual term in the water balance, actually contains all the errors inherent in the measurement of precipitation and the various forms of runoff.

- **Direct measurement methods:** Evapotranspiration from soil surfaces has been measured directly using soil containers variously referred to as evapotranspiration tanks, evapotranspirometers, and lysimeters. Reliable direct measurement of evapotranspiration is seldom achieved, however, due to the difficulty in maintaining conditions within an experimental container which accurately represent natural vegetal and soil moisture conditions outside the container. The best of such measurement devices are large in diameter (e.g., 15 feet), in order to allow uninhibited root growth development; they are also typically provided with a mechanism for applying negative pressure at the base to simulate drainage characteristics in the natural soil profile.

- **Estimation from meteorological data:** A number of empirical techniques have been developed to relate evapotranspiration to readily available climatic data, such as temperature and cloud cover. For example, equations and methodologies have been proposed by Thornwaite and Mather (1955), Blaney and Criddle (1950), Penman (1948), Priestly and Taylor (1972), and Lowry and Johnson (1942). These methods are summarized in Veihmeyer (1964) and Linsley et al. (1982).

For large, permanent water bodies, transpiration is not significant, and evapotranspiration is equivalent to free-water (lake) evaporation (Figure E-8). On land, transpiration from plants is usually considered to be approximately equal to free-water evaporation, provided that the supply of water to the plants is not limited. Therefore, free-water evaporation is also approximately equal to "potential evapotranspiration" from vegetated soil surfaces, as described below.

Thornwaite (1946) defines "potential evapotranspiration" as the amount of water which would be lost from a soil surface completely covered with vegetation if there were sufficient water in the soil at all times for the use of the vegetation. When soil moisture content is near field capacity (i.e., the maximum moisture which the soil can retain without producing continuous downward percolation), actual evapotranspiration approximately equals potential evapotranspiration. As the soil dries, however, evapotranspiration diminishes with decreasing soil moisture content and becomes zero when the soil moisture content reaches its wilting point (i.e., the moisture content below which moisture is unavailable for withdrawal by plants). Throughout this drying process, actual evapotranspiration is less than potential evapotranspiration. Figure E-9 indicates the monthly relationship between average precipitation, potential evapotranspiration and actual evapotranspiration, as calculated by Thornwaite and Mather (1955) at Camden, South Carolina. The example depicted in Figure E-9 is described by the above authors as follows:

> In this example, precipitation and water need do not coincide. There is too much precipitation in winter and too little in summer. In mid-autumn, water need falls below precipitation. For a while, the surplus rainfall replaces soil moisture that had been used up previously. From then on the surplus water raises ground-water levels and produces surface and subsurface runoff. But it is of little benefit to plants. In spring, both transpiration and evaporation increase rapidly and soon water need surpasses precipitation. The excess demands for water are satisfied in part by the current precipitation and from the stored soil moisture reserves. That part of the total water demand which is not met in this manner is known as the moisture deficit. As the soil dries and a smaller proportion of the water demand is satisfied through precipitation and the utilization of stored soil moisture, the deficit increases and the plants begin to suffer severely from the lack of moisture. The actual loss of water from the soil and plants, the actual evapotranspiration, is equal to the water needs or potential evapotranspiration during those periods when precipitation exceeds water need. However, when precipitation is less than the demands for water the actual evapotranspiration is less than the potential, and a moisture deficit equal to the differences between these two quantities exists.

To summarize the foregoing discussion, it is important to maintain the distinction between potential and actual evapotranspiration. Actual evapotranspiration is the "real" term which is required for detailed hydrologic studies and water balance analyses. However, actual evapotranspiration is very difficult to measure and can often be estimated only on the basis of potential evapotranspiration. Over permanent water bodies, the two terms are essentially equal, and they are also equal to free-water evaporation (Figure E-8). Over land, however, actual evaporation is typically less than potential evapotranspiration, and it is limited by available soil moisture. When soil is fully saturated (i.e., to field capacity), actual evapotranspiration over land surfaces is usually considered equal to potential evapotranspiration and to free-water evaporation.

Evapotranspiration varies significantly on a geographic basis (Figure E-8) and also seasonally within a given location (Table E-1). Although it also varies from year to year, this annual variation is typically much less than that of precipitation or total runoff. Some studies have shown that extreme variations in annual evapotranspiration fall within a range of approximately plus or minus 25 percent of their mean annual values (Lowry and Johnson 1942). This comparatively small variation reflects the relative stability, from year to year, of those climatic factors which most directly affect evapotranspiration, such as temperature, sunshine, and wind.

The primary source of evapotranspiration data in the United States is the National Weather Service, which maintains and publishes pan evaporation data as part of its monthly and annual *Climatological Data* reports. Information concerning the National Weather Service and the National Climatic Data Center were provided in Section E.2.2.

SOURCE OF EVAPOTRANSPIRATION DATA IN THE U. S.

The national Weather Service publishes evapotranspiration data in its monthly and annual *Climatological Data* reports. (Section F.2.2)

E.2.4 RUNOFF

Precipitation falling over a watershed is either returned to the atmosphere via evapotranspiration or discharged from the watershed as runoff. The three components which make up total runoff—surface runoff, interflow, and groundwater flow—are actually part of a continuum which represents the total water production or "yield" from the watershed. Surface drainage may reach a point along its path where it infiltrates the ground and becomes interflow or groundwater flow. Conversely, water flowing beneath the ground on its way to a stream may, under the right hydrogeologic conditions, discharge to the ground surface as a spring or seep, and thereby become surface runoff. However, despite the actual overlap and interrelationships which exist between these runoff terms, their distinction provides a useful basis for hydrologic description.

The three components which make up total runoff—surface runoff, interflow, and groundwater flow—are actually part of a continuum which represents the total water production or "yield" from the watershed.

Runoff may be expressed as a volume or a depth. Volumetrically, it is equal to the total amount of water discharging from a drainage basin over a given period of time. If this volume is divided by the area of the drainage basin, it can be converted to depth, which is the more common unit for expressing runoff. In the United States, runoff is usually expressed in units of inches. The rate of runoff from a watershed is referred to as the "discharge." Discharge may be expressed in terms of inches of runoff per hour over a given drainage area or, more commonly, as cubic feet per second (cfs). The latter term is independent of drainage area and is the common unit in which streamflow measurements are expressed. (One inch per hour of runoff over a one acre drainage area is almost exactly equal to one cubic foot per second.) A term directly related to runoff is "unit discharge," which is equal to the average discharge for a given time period divided by the drainage area producing that discharge. Unit discharge is typically expressed in units of cubic feet per second per square mile (csm).

E.2.4.1 Total Runoff

The total runoff from a watershed is often referred to as "streamflow," since virtually all runoff components ultimately find their way to perennial (i.e., permanent) or intermittent streams draining the watershed. The relative contribution of the different runoff components to streamflow depends upon meteorological and watershed characteristics and also upon time frame. During storms (i.e., precipitation events of sufficient magnitude to produce a short-term increase in streamflow), surface runoff and interflow are the dominant components of total runoff. Because they create a similar response and cannot practically be measured separately, these two terms are commonly grouped together and referred to as "direct runoff." On the other hand, during dry periods, the total runoff or streamflow in channels is sustained by groundwater flow, which is also commonly referred to as "base flow."

The determination of total runoff from a watershed, and its time distribution, are key aspects of many hydrologic investigations. The prediction of direct runoff during storms is critical to the design of drainage networks, stormwater management systems, reservoir spillways, and a host of other hydraulic structures. On the other hand, water supply and irrigation studies require the prediction of low flows sustainable during extended dry weather conditions or droughts. Many hydrologic designs (e.g., reservoirs, created wetlands) require an evaluation of both storm-related and low-flow hydrology and therefore involve all runoff components. The following aspects of total runoff, or streamflow, are relevant to the siting and design of many wetland restoration projects that depend upon an adequate supply of water from a drainage basin:

- **The geographic distribution of annual runoff in the United States is highly variable.** As indicated by Figure E-10, total runoff varies from a range of approximately 20 to 40 inches per year in the humid Northeast, to less than 1 inch per year throughout large areas of the arid Southwest.

- **The seasonal distribution of runoff is also quite variable throughout most of the United States.** Figure E-11 indicates that maximum runoff generally occurs in spring to early summer throughout most of the country. But this is not true in some regions (e.g., the Southeast), and even in those where it is, the pattern of runoff throughout the year is quite variable by region.

- **At a given measuring point within a watershed, average annual total runoff is approximately proportional to precipitation.** As shown by Figure E-12, however, the relationship is not a perfect one (i.e., there is a considerable scatter of points from the runoff-precipitation line). This demonstrates that, while annual precipitation is the primary factor affecting average annual runoff, other meteorological and watershed factors also exert an influence.

- **Within a given watershed or subwatershed, provided that meteorological or hydrogeological conditions do not vary greatly, average annual total runoff (streamflow), expressed in inches, is generally independent of surface area.** This is an important relationship, since it allows the extrapolation of runoff data from gaged to ungaged portions of a watershed (e.g., from gaged streamflow stations to a proposed ungaged wetland restoration site). It should be emphasized, however, that this independence with respect to area applies only to long-term (i.e., annual) average runoff and not to runoff conditions associated with floods or droughts. The distinction is discussed further in Section E.2.6.

The measurement of total runoff, or streamflow, is much easier than the measurement of its individual components. There are numerous methods and publications concerning the measurement of discharge in open channels. These methods generally involve either the use of velocity meters to calculate and sum discharge across a channel section or else the calculation of discharge through fixed structures (e.g., culverts, weirs, flumes) using established hydraulic formulas. Typically, such discharge measurements are made at different water levels (stages), and then a relationship, referred to as a rating curve, is established between stage and discharge at a station. The United States Geological Survey (USGS) maintains an extensive stream gaging network throughout the country. The gages operated by the USGS record stage on an intermittent or continuous basis, and the resulting data are converted to discharge values by means of a station rating curve. Figure E-13 illustrates the typical format used by the Water Resources Division of the USGS in its annual state-wide publications of streamflow records for gaging stations across the United States (United States Geological Survey 1990). The example shown on Figure E-13 includes discharge records of a gage in the State of Ohio for Water Year 1989. (USGS water years begin on October 1 and end on September 30.)

A great deal of information is contained in such records, including: station information (location, drainage area, etc.), daily and monthly average discharges, extreme discharges for the present year and for the period of record, average discharge and average total runoff (streamflow) for the present year and for the period of record. For example, for the stream gage shown in Figure E-13, the drainage area tributary to the stream gage is approximately 150 square miles. Using this area and the total runoff volume at the gage (computed as the product of discharge and time), the total watershed runoff can be calculated as 10.79 inches for Water Year 1989, with an average value of 11.50 inches per year for the 16-year period of record. It should be noted that the runoff computed using records such as those shown in Figure E-13 always represents total runoff. Differentiation between its components (i.e., direct runoff and base flow) is possible using techniques discussed in the following section.

E.2.4.2 Direct Runoff

Direct runoff, consisting of surface runoff plus interflow (Figure E-1), is driven by precipitation and is, therefore, storm-related. The direct runoff process, or "runoff cycle," may be visualized by referring to Figure E-14. Although there are actually an infinite number of possible rainfall-runoff combinations and sequences, this simplified schematic diagram identifies four separate phases of the runoff cycle.

- **Phase 1 is the period prior to the beginning of rainfall.** If there has been an extended dry period prior to the storm, soil moisture will be depleted, and groundwater and surface water levels will be depressed throughout the watershed. Streamflow will be either low in perennial streams or absent altogether in intermittent streams; lake and reservoir levels will be down; the water surface in adjacent wetlands may have dropped below the ground surface.

- **Phase 2 includes the initial period of rainfall.** It produces little direct runoff, except for that precipitation falling directly upon stream channels or connected impervious surfaces. The precipitation during this phase instead goes to satisfy "initial abstractions," which include temporary storage in surface depressions, interception by vegetation, infiltration into the ground and subsequent replenishment of depleted soil moisture. Most of this initial abstraction is subsequently returned to the atmosphere as evapotranspiration.

- **Phase 3 includes the continuation of rainfall beyond the point where initial abstractions are satisfied, with the net rainfall rate exceeding the rate of soil infiltration.** During this phase, direct runoff to stream channels occurs as a combination of surface runoff and interflow. As the rain continues, water levels rise in groundwater, streams, lakes and adjacent wetlands.

- **Phase 4 is the drying period between storms.** Direct runoff ceases when rainfall either stops or drops to a rate below the soil's infiltration capacity. After the cessation of rainfall, accumulated water stored within the watershed above ground (in floodplains, wetlands, lakes and reservoirs) and below ground (as soil moisture) is gradually released to groundwater or returned to the atmosphere by evapotranspiration. During this time period, water levels above and below ground initially rise but then gradually return to their Phase 1 positions.

Among the many simplifications in the above description, one of the most significant is the assumption of dry soil prior to the commencement of rainfall. Actually, depending upon the previous history of precipitation, the soil may range anywhere from very dry to fully saturated. Across this range, a very great difference can be expected not only in the physical processes which make up the runoff cycle but also in the amount of direct runoff produced by a given amount of precipitation. In general, if there has been significant prior precipitation (i.e., a high "antecedent moisture condition"), the same rainfall will produce a significantly greater direct runoff than if it were to fall upon a dry watershed. This topic is addressed further under the discussion of methods for predicting direct runoff.

The runoff cycle described above is influenced considerably by the infiltration capacity of soil. Infiltration rate refers to the rate at which water actually enters the soil. It is equal to the infiltration capacity of the soil or the rainfall rate, whichever is less (Figure E-14). Infiltration is a complex process, which depends upon a number of variables, including: the porosity and permeability of the soil itself; the type of vegetative cover; the soil moisture content; the pattern of rainfall; and the condition of the soil surface, which might limit surface entry rate. The infiltration capacity of a soil typically decreases with time during a rainfall event and eventually approaches a constant value, as pore spaces within the soil become filled with water and the soil moisture content approaches field capacity. Infiltration can be directly measured using infiltrometers, calculated on the basis of rainfall-runoff relationships, or estimated using a variety of empirical equations or infiltration indices (Musgrave and Holtan 1964).

Most reliable data concerning actual infiltration rates are site-specific and come from direct measurements or from rainfall-runoff calculations. These data show a broad range of values. Linsley and Franzini (1972), for example, report that infiltration capacity of bare soil under average summer conditions and after one hour of rainfall varies from 0.01 inches per hour for heavy clay soils to 1.0 inches per hour for loose sandy soils. Considerably higher rates (up to several inches per hour) have been measured for vegetated soil surfaces, with marked variations depending upon the type of vegetation. As discussed below, most methods for predicting runoff do not require the direct calculation of infiltration. Rather, infiltration effects are included implicitly within other factors such as the runoff coefficient of the rational formula or runoff curve number of the Soil Conservation Service method (Tables E-2a and E-2b).

Because direct (storm) runoff has a major impact upon many human activities, it has been studied extensively. In fact, almost all texts on quantitative hydrology deal with this subject at length. Of the numerous methods which have been developed for predicting direct runoff, three of the most common are described in the following sections.

E.2.4.2.1 Unit Hydrograph Method: The concept of a unit hydrograph was introduced by Sherman (1932). Since then, it has been expanded and refined, until it is now one of the primary tools used by hydrologists for flood analysis and forecasting. Application of the unit hydrograph method requires that an independent evaluation be made to determine the relationship between rainfall and runoff volume (e.g., the Soil Conservation Service method, as discussed in the following section). For this reason, and because the derivation and use of unit hydrographs is a relatively time-consuming and data-intensive process, the method will seldom have practical application value for wetland restoration projects. However, the unit hydrograph method does demonstrate some important hydrologic concepts and is presented primarily for this reason.

A "hydrograph" is a plot of discharge versus time, as indicated by Figure E-15. The area under a hydrograph is equal to the volume of total runoff (streamflow) occurring during the time period of the hydrograph and passing the measuring point at which the hydrograph is recorded, i.e., the gaging station. For a storm hydrograph, this volume includes both direct runoff and groundwater flow (base flow). In order to evaluate direct runoff only, it is necessary to separate the hydrograph into its direct runoff and base flow components. A number of methods have been proposed for base flow separation (e.g., Linsley et al. 1982); however, they are beyond the scope of this discussion. Figure E-15 indicates a typical estimated base flow recession curve (Segment A-B-C), which connects the rising and falling limbs of the total storm hydrograph.

The unit hydrograph is defined as the hydrograph produced by a single unit (e.g., one inch) of direct runoff from a rainfall of specified duration. It can be constructed from an actual storm hydrograph, given the corresponding amount and effective duration of storm rainfall. Once this unit hydrograph for a watershed has been determined, it theoretically represents the "fingerprint" of the watershed and can be used to predict the actual hydrograph corresponding to any other combination of rainfall/runoff volume (inches) and duration. For example, on Figure E-15, the direct runoff volume is equal to the area between the total hydrograph and the estimated base flow recession curve (Area A-B-C-D). It can be calculated as shown in Figure E-15 and, for the known watershed area, converted to an equivalent direct runoff in inches. The unit hydrograph ordinate at any time is calculated by dividing the corresponding direct runoff discharge (i.e., the total hydrograph discharge minus the base flow discharge) by this direct runoff in inches. The above division establishes the unit hydrograph as a hydrograph corresponding to one inch of direct runoff. The procedure is illustrated in Figure E-15: it shows a 3-hour unit hydrograph for the watershed under study.

Once the unit hydrograph has been determined, it can be used to estimate the runoff hydrograph for other storms of different magnitude and duration. For example, by the principle of linearity which is central to the unit hydrograph theory, a storm with an effective duration of 3 hours, producing a direct runoff of 1.40 inches (calculated separately by volumetric rainfall-runoff relationships), would result in a direct runoff hydrograph whose ordinates were exactly 1.40 times those of the unit hydrograph. Superimposing this upon an estimated base flow hydrograph would produce an estimated total hydrograph for such a storm. There are methods to convert the duration of the design storm from that upon which the unit hydrograph is based. These are beyond the present scope, but they are described in many texts on quantitative hydrology and streamflow forecasting (e.g., Chow 1964).

E.2.4.2.2 Soil Conservation Service (SCS) Method: The United States Department of Agriculture Soil Conservation Service (SCS) has developed a well-known and widely used method for estimating the direct runoff volume, peak rate, and hydrograph for small- to medium-sized watersheds. The SCS method is presented in detail within the *National Engineering Handbook*, Section 4, "Hydrology" (U.S. Soil Conservation Service 1985) which is commonly referred to as "NEH-4." The SCS method itself is often referred to as the "soil-cover-complex" method, for reasons discussed below.

The key parameter in the SCS method is the "runoff curve number" (CN). The curve number is a function of both hydrologic soil group and land use. All soils occurring within the United States have been categorized by the SCS into four groups: A, B ,C, or D. This grouping reflects the ability of a soil to absorb water by surface infiltration and subsurface percolation. Group A soils (e.g., sands and gravels) have a high infiltration capacity and a relatively low runoff potential; Group D soils (e.g., clays) have a low infiltration capacity and high runoff potential; Group B and C soils are intermediate. For a given site or location, the hydrologic soil groups(s) can be determined by a two-step process. First, the soil type (e.g., Chester loam) is identified by referring to the appropriate county SCS soil survey. (SCS has mapped soils, by county, for most areas within the United States.) Second, for a given soil type(s), the hydrologic soil group can be determined by referring directly to NEH-4 or to other SCS publications such as Technical Release No. 55 (TR-55) (U.S. Soil Conservation Service 1986) or to the design manuals published by many local agencies which have adopted the SCS method for drainage and/or stormwater management design.

The runoff potential of a watershed is a function of not only hydrologic soil group but also land use. Tables E-2a and E-2b provide the runoff curve number (CN) for both these parameters. For the typical case of a watershed with multiple soil groups and land uses, the curve number is calculated by dividing the watershed into subareas and calculating an area-weighted composite value for "CN." This value can be used to estimate direct runoff volume (Qd) from the following two equations:

$$S = (1{,}000/CN) - 10 \qquad [2.2]$$

$$Qd = (P-0.2S)^2 / (P+0.8S) \qquad [2.3]$$

where, S = potential abstraction (inches)
CN = runoff curve number (dimensionless)
P = total storm rainfall (inches)
Qd = direct runoff (inches)

In the above equations, the potential abstraction (S) is the maximum retention capability of the soil, in inches. It includes the initial abstraction (surface depression storage, interception by vegetation, and "early" infiltration) plus the continuing infiltration which occurs after runoff begins.

Based upon data from small watersheds, the SCS has developed the following empirical relationship between initial abstraction (Ia) and potential abstraction (S):

$$Ia = 0.2S \quad [2.4]$$

Considering that significant direct runoff does not begin until the initial abstraction is satisfied, and referring to Equations 2.2, 2.3 and 2.4, it can be seen that there is a threshold value of storm rainfall (P) below which direct runoff is not produced. This can also be determined by referring to Figure E-16 and Table E-3, which show the SCS rainfall-direct runoff relationship in graphical and tabular form, respectively.

The SCS method can also be used to estimate the peak discharge (qp) and complete storm hydrograph for a watershed. The procedure is based upon unit hydrograph theory, using a standard, synthetic unit hydrograph which SCS has derived empirically from studies of a large number of watersheds varying widely in size and geographical location. A complete description of the development and use of this method is presented in NEH-4. Its actual application to compute peak discharge and direct runoff hydrographs is presented concisely in TR-55. The following information must be known:

- **Time of concentration (Tc):** This is the time which it takes for runoff to travel from the most hydraulically distant part of the watershed to the point of reference. It typically consists of overland flow plus channelized flow time, and it can be estimated using the methods presented in NEH-4, TR-55, or most hydrology textbooks and references.
- **Watershed drainage area (A)**
- **Twenty-four hour rainfall (P24):** As previously described, this information can be obtained, for various storm frequencies, from the *Rainfall Frequency Atlas for the United States - Technical Paper 40* (U.S. Weather Bureau, 1961). Precipitation maps from this reference are contained in many texts and design manuals, including TR-55.

TABLE E-2a

RUNOFF CURVE NUMBERS FOR THE SCS METHOD
(after United States Soil Conservation Service 7R-5S 1986)

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	**Average percent impervious area***	**A**	**B**	**C**	**D**
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.):					
Poor condition (grass cover < 50%)	*	68	79	86	89
Fair condition (grass cover 50% to 75%)	*	49	69	79	84
Good condition (grass cover > 75%)	*	39	61	74	80
Impervious areas:					
Paved parking lots, roads, driveways, etc. (excluding right-of-way)	*	98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)	*	98	98	98	98
Paved; open ditches (including right-of-way)	*	83	89	92	93
Gravel (including right-of-way)	*	76	85	89	91
Dirt (including right-of-way)	*	72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)	*	63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)	*	96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town house)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
½ acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)	*	77	86	91	94

* Applies to urban districts and residential districts only.

- **Rainfall distribution:** The distribution of rainfall, as well as the total amount, affect the peak rate and timing of runoff. Using National Weather Service data, the SCS has developed four synthetic 24-hour rainfall distributions for different regions of the United States. Type I and IA represent the Pacific maritime climate; Type II represents the Gulf of Mexico and Atlantic coastal areas; and Type III represents the rest of the country. Using maps such as that provided in Appendix B of TR-55, the rainfall distribution type must be estimated, based upon proposed site location, in order to use the SCS method for prediction of peak discharge rate and storm hydrograph.

- **Runoff curve number (CN):** This value, determined as previously described, is used to calculate the volume of direct runoff (Qd). Peak discharge and hydrograph discharge values are based upon this calculated "Qd" value.

Given the above information, the peak discharge can be calculated as follows. First, the initial abstraction (Ia) is calculated using Equations 2.2 and 2.4, which when combined yield:

$$Ia = 200/CN - 2 \qquad [2.5]$$

Next, the ratio of initial abstraction to 24-hour precipitation (Ia/P24) is calculated. With this value, Figure E-17 can be used to determine the unit peak discharge (qu), which is simply the peak discharge per unit watershed area per inch of direct runoff. Multiplying "qu" by the actual drainage area, A (square miles), and by the actual runoff volume, Qd (inches), yields the value for peak discharge, qp (cubic feet per second or cfs).

In addition to the above graphical method for determining peak discharge, TR-55 provides multiple tables for estimating the direct runoff hydrograph as a function of Tc, Ia/P24, rainfall distribution type, and travel time downstream from the reference point (Tt). Table E-4 is an example of such a table. As a storm hydrograph moves downstream (i.e., as travel time increases), its peak discharge is offset in time and attenuated by a phenomenon known as channel flood routing. Although beyond the scope of this discussion, the result of this flood routing can be seen from Table E-4, where the peak discharge is successively reduced and delayed in a downstream direction.

The SCS method for predicting direct runoff is powerful, flexible, and easy to use. For a more complete description of it, the above-cited texts should be consulted. Although such a description is beyond the present scope, several of the key features and limitations of the method are described below:

- **For reasons discussed previously, the runoff potential of a soil depends upon its infiltration capacity and consequently upon its moisture content at the beginning of a rainfall event.** The SCS has defined "antecedent moisture content" (AMC) as the total amount of rainfall occurring during the five days previous to the storm and has established three AMC groups. The first, Group I, represents the driest condition with the lowest potential runoff; Group II is the average condition; and Group III represents an almost saturated condition with the highest runoff potential. These groups are defined quantitatively in NEH-4. All of the preceding figures and tables are based upon average antecedent moisture conditions. NEH-4 also provides adjustment factors for wetter or dryer conditions.

TABLE E-2b

RUNOFF CURVE NUMBERS FOR THE SCS METHOD
(after United States Soil Conservation Service TR-55 1986)

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing	Poor Fair Good	68 49 39	79 69 61	86 79 74	89 84 80
Meadow—continuous grass, protected from grazing and generally mowed for hay	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element	Poor Fair Good	48 35 30	67 56 48	77 70 65	83 77 73
Woods—grass combination (orchard or tree farm)	Poor Fair Good	57 43 32	73 65 58	82 76 72	86 82 79
Woods	Poor Fair Good	45 36 30	66 60 55	77 73 70	83 79 77
Farmsteads—buildings, lanes, driveways, and surrounding lots	—	59	74	82	86

- **The method described above is generally limited to watersheds of approximately 2,000 acres in size or less, without a high percentage of reservoir and/or wetland areas, and without many different subareas exhibiting greatly different runoff characteristics.** For larger or more complex watersheds, the basic methodology is still applicable, though it should be refined by subdividing the watershed, superimposing the effects of different subareas, and routing subarea hydrographs through channels and reservoirs as appropriate. For this purpose, the SCS has developed a computer program, documented in Technical Release No. 20 (U.S. Soil Conservation Service 1983), which is capable of applying the SCS method to large and/or complex watersheds.

- **The SCS method represents a compromise between oversimplification and practical utility.** Its flexibility and ease of application are strong advantages of this method. By comparison, the site-specific unit hydrograph method is more limited in scope, and it requires a much greater expenditure of data-gathering and analytical time. On the other hand, the Rational Formula method (discussed below) is very simple to apply but extremely limited from both theoretical and practical standpoints. Nevertheless, despite the relative advantages of the SCS method for predicting direct runoff, its foundation should be kept in mind. The rainfall-runoff relationships, as well as the hydrograph development techniques, are based upon the use of empirical relationships derived from widely diverse, primarily agricultural watersheds, which have been condensed into practical, but ultimately generic, equations and procedures. Notwithstanding this important caveat, the SCS method is probably the most practical and widely used method today for predicting direct runoff volume and rate for simple to moderately complex hydrologic designs.

E.2.4.2.3 Rational Formula Method: The Rational Formula was introduced in the late 19th century (Kuichling 1889) and has since become the mainstay of drainage designers in the United States. The method allows the calculation of peak storm discharge according to the following formula:

$$qp = ciA \quad [2.6]$$

where, qp = peak discharge (cfs)
c = runoff coefficient (dimensionless)
i = rainfall intensity (inches per hour)
A = drainage area (acres)

The equation is dimensionally consistent, since 1 cubic foot per second is approximately equal to one acre-inch per hour. The underlying theory behind the Rational Formula is that a rainfall of constant intensity will, after an initial period of time, produce a constant storm discharge. More specifically, some of the key assumptions involved in the formula are:

- That the frequency of peak discharge and rainfall intensity are the same;
- That the value of runoff coefficient is independent of antecedent moisture conditions;
- That the relationship between peak discharge and rainfall intensity is strictly linear;
- That the value of runoff coefficient is the same for storms of various frequencies and for all storms over a given drainage area; and
- That rainfall intensity is uniform over the drainage area.

In fact, these assumptions are seldom realized, except for very small, impervious drainage areas, such as parking lots or other paved areas. However, despite its many theoretical shortcomings, the Rational Formula continues to be the most widely used method for storm drainage design in the United States. In an excellent critique of the method, McPherson (1974) suggests that the principal reasons for this are the simplicity of the formula, the considerable latitude in the selection of input parameters, and the fact that the method is almost impossible to verify. (A drainage system designed by the Rational Formula cannot be correlated with a single storm frequency, meaning that one portion of the system may be flooding while the other is considerably under-used.)

TABLE E-3
SCS RAINFALL—DIRECT RUNOFF TABLE
(after United States Soil Conservation Service TR-55 1986)

	Runoff depth for curve number of –												
Rainfall	40	45	50	55	60	65	70	75	80	85	90	95	98
	Inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

In addition to its theoretical shortcomings, the Rational Formula is limited to the calculation of peak storm discharge. It cannot be used to calculate the total volume of runoff, nor can it be defensibly applied to determine the time-history of runoff (i.e., the hydrograph), although some drainage designers have attempted to do so by extending even further the list of assumptions indicated above. It should also be noted that the runoff coefficient (c) in the Rational Formula is only intended for the calculation of peak discharge. It does not, as is sometimes assumed, represent the percentage of precipitation which becomes runoff during a storm. In other words, it should not be used to estimate the volume of storm runoff.

For the above reasons, the Rational Formula has little use in the design of most wetland replacement projects. Its application is not addressed further here. Because of the widespread use of this method, however, it is discussed at length in most hydraulic engineering design manuals.

E.2.4.3 Groundwater Flow

E.2.4.3.1 Definitions and Special Topics: The term "groundwater" refers to water occurring in the fully saturated zone of soil and rock beneath the earth's surface. The top of this fully saturated zone is referred to as the "water table." Within the hydrologic cycle (Figure E-1), groundwater has the lowest priority claim upon precipitation; it is derived from that fraction of total precipitation remaining after actual evapotranspiration needs have been satisfied and direct (storm-related) runoff has occurred. Although groundwater flow (base flow) makes up a relatively small percentage of the total runoff (streamflow) occurring during storm events (Figure E-15), much of the approximately 1,200 billion gallons per day of average annual streamflow in the United States is sustained by discharge from groundwater reservoirs (United States Geological Survey 1986). The subject of groundwater and groundwater flow is an extensive one, which is comprehensively addressed in a number of texts. Included among these are: *Groundwater* (Freeze and Cherry 1979); *Applied Hydrogeology* (Fetter 1980); and *Groundwater and Wells* (Driscoll 1986). Although a full discussion of this subject is beyond the present scope, several key groundwater topics are presented in summary fashion below. These topics have been selected on the basis of their potential relevance to wetland replacement design.

Figure E-18 indicates a simplified schematic representation of a shallow groundwater flow system. Precipitation which infiltrates the ground surface flows downward through an unsaturated to partly saturated zone referred to as the "vadose zone." Upon reaching the water table, this infiltrating water flows in a direction of decreasing "hydraulic head," i.e., decreasing energy potential, as typically measured by the water surface elevation in shallow wells. For most practical applications, this shallow groundwater flow can be assumed to occur in a direction from generally high to low ground surface elevations. The water table, in other words, is essentially a subdued reflection of surface topography. Surface water bodies (streams, lakes, oceans) and adjacent wetlands typically occur at topographic low areas within the landscape. These topographic lows are also locations where, typically, shallow groundwater discharges to the surface as base flow into streams, or seepage into lakes, reservoirs, etc.

The following definitions and discussion are intended to amplify the above descriptive summary, to consider further some of the generalized assumptions upon which it is based, and to identify some of the key groundwater-related topics of importance to a wetland replacement designer:

TABLE E-4

SCS TABULAR HYDROGRAPH (CSM/IN) FOR RAINFALL TYPE I

HYDROGRAPH TIME (HOURS)

TRVL TIME (HR)	9.0	9.3	9.6	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	11.0	11.2	11.4	11.6	11.9	12.0	12.3	12.6	13.0	13.5	14.0	14.5	15.0	15.5	16.0	17.0	18.0	20.0	24.0
IA/P = 0.10														* * * TC =0.1 HR * * *														IA/P = 0.10				
0.0	30	40	56	183	337	304	326	155	122	107	93	81	73	66	60	56	54	52	49	46	44	40	36	32	30	29	28	27	26	24	20	13
.10	26	35	48	93	153	276	428	360	223	156	123	103	88	72	65	59	56	54	51	47	45	42	37	33	30	29	28	28	26	24	21	13
.20	23	30	41	60	82	129	227	361	360	269	196	147	118	85	71	63	58	55	53	49	46	43	39	35	31	29	29	28	26	24	21	14
.30	22	29	39	56	73	111	188	303	341	293	227	173	136	94	75	65	60	56	54	50	47	43	39	35	31	29	29	28	26	25	21	14
.40	18	25	34	46	53	66	96	157	255	312	300	251	199	126	90	73	64	59	56	52	48	44	40	36	32	30	29	28	26	25	21	14
.50	15	24	32	44	50	61	84	133	214	280	293	265	221	144	99	77	66	60	56	52	49	45	41	37	32	30	29	28	27	25	21	14
.75	14	19	25	34	38	43	49	62	88	134	190	234	252	221	162	115	87	71	63	56	52	47	43	39	35	31	29	29	27	25	22	15
1.0	11	14	19	26	28	31	34	38	44	52	68	98	141	222	238	191	139	101	79	63	56	51	45	41	37	33	30	29	27	26	22	15
1.5	9	10	13	17	18	20	22	25	27	30	34	38	44	74	132	191	211	190	151	101	73	58	50	45	41	37	33	30	28	27	23	16
2.0	6	7	9	11	12	13	14	15	16	18	20	22	24	29	38	58	97	148	193	193	141	89	61	51	46	41	37	33	29	27	24	17
2.5	4	5	7	8	9	9	10	11	11	12	13	14	15	19	23	29	39	58	93	154	181	147	87	61	51	45	41	37	30	28	25	18
3.0	2	3	5	6	6	7	7	8	9	9	10	10	11	13	15	19	23	28	39	72	124	170	138	96	61	50	45	40	33	29	26	19
IA/P = 0.30														* * * TC =0.1 HR * * *														IA/P = 0.30				
0.0	0	0	0	61	195	343	232	129	113	103	91	81	76	71	66	64	62	61	59	56	54	51	47	43	40	40	39	39	37	36	31	21
.10	0	0	0	12	45	145	277	247	169	131	112	98	87	76	70	65	64	62	60	57	55	53	49	44	40	40	39	39	38	36	32	21
.20	0	0	0	9	33	107	220	238	192	151	125	107	94	79	71	66	64	62	61	58	56	53	49	45	41	40	40	39	39	36	32	21
.30	0	0	0	1	6	24	79	173	216	200	168	139	115	90	77	70	66	64	62	59	57	54	50	46	41	40	40	39	38	36	32	22
.40	0	0	0	1	4	17	59	135	189	196	177	152	129	97	81	72	67	64	63	60	57	54	51	46	42	40	40	39	38	36	32	22
.50	0	0	0	0	0	3	12	43	104	161	185	180	161	121	93	79	71	66	64	61	58	55	52	48	43	40	40	39	38	37	33	22
.75	0	0	0	0	0	1	5	18	49	92	130	153	159	142	114	92	79	71	66	63	60	56	53	49	44	41	40	40	38	37	33	23
1.0	0	0	0	0	0	0	0	0	2	9	27	56	92	144	152	128	103	86	75	67	63	59	55	51	47	43	40	40	39	37	34	24
1.5	0	0	0	0	0	0	0	0	0	0	0	2	6	32	79	121	136	127	109	95	72	64	58	55	51	47	43	40	39	38	34	25
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	33	70	105	126	118	97	75	63	58	54	50	46	42	40	39	35	26
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	32	63	105	118	100	75	63	58	54	50	46	40	39	36	27
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	12	43	94	112	96	74	63	58	54	50	42	40	37	28
IA/P = 0.50														* * * TC =0.1 HR * * *														IA/P = 0.50				
0.0	0	0	0	0	0	3	13	28	39	44	45	46	46	48	49	51	53	54	54	55	56	55	53	50	50	49	49	49	49	48	45	32
.10	0	0	0	0	0	2	9	22	33	41	44	45	46	48	49	50	52	54	54	54	56	55	53	50	50	49	49	49	49	48	45	32
.20	0	0	0	0	0	0	1	7	17	28	36	41	44	46	48	49	51	53	54	54	56	56	54	51	50	50	49	49	49	48	45	32
.30	0	0	0	0	0	0	0	1	5	13	23	32	38	44	47	48	50	51	53	54	54	55	54	52	50	50	49	49	49	48	46	33
.40	0	0	0	0	0	0	0	0	3	10	18	27	34	43	46	48	49	51	53	54	54	55	54	52	50	50	49	49	49	48	46	33
.50	0	0	0	0	0	0	0	0	0	2	7	15	23	36	43	46	48	50	51	53	54	55	55	53	50	50	49	49	49	48	46	34
.75	0	0	0	0	0	0	0	0	0	1	3	7	13	27	37	43	46	48	50	52	54	55	55	54	51	50	50	49	49	48	46	34
1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	20	32	40	45	47	50	52	54	55	54	52	50	50	49	49	49	47	36
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	13	23	33	42	47	51	54	55	54	53	50	50	49	49	48	37
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	12	25	37	46	51	54	55	54	52	50	49	49	48	39
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	15	31	45	51	53	55	54	52	50	49	48	41
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	14	32	45	51	53	54	54	51	49	48	42

RAINFALL TYPE = I * * * TC = 0.1 HR * * * SHEET 1 OF 10

- **Aquifers:** An aquifer is defined as "a saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients" (Freeze and Cherry 1979). Since the permeability of a geologic unit can vary over a continuum of wide-ranging values (hydraulic conductivity, below), so, too, the concept of an aquifer must be regarded as a continuum. While there is little disagreement that a saturated, free-draining gravel unit would be classified as an aquifer, or that a saturated unit of dense clay would not, there are an infinite combination of intermediate soil/rock textures and structures for which the above definition is imprecise and can be applied only in a relative sense. Although all soils and rocks have some capability to transmit water, the term "aquitard" has been applied to those less permeable units whose ability is limited. At any location, several aquifers may occur at different depths. The uppermost aquifer, whose top surface is formed by the water table, is referred to as an "unconfined," or "water table," aquifer. At lower depths, "confined" aquifers may be encountered which are bounded both above and below by geologic units of significantly lower permeability, or aquitards. Confined and unconfined aquifers behave differently and are described by different sets of groundwater flow equations. However, wetland applications almost always involve shallow groundwater flow systems in unconfined aquifers. Therefore, the following discussion will focus upon these water table aquifers.

- **Hydraulic conductivity:** Hydraulic conductivity (K) reflects the ability of a porous medium to transmit fluid. According to Darcy's Law (Section E.2.4.3.2), the rate of groundwater flow through an aquifer is directly proportional to its hydraulic conductivity. The term is often used interchangeably with "permeability," although permeability, more precisely, is a property of the porous medium alone, whereas hydraulic conductivity is also a function of the fluid. For our purposes, the distinction is unimportant except in terms of measurement units. Hydraulic conductivity has units of length per time and is typically expressed as centimeters per second or cm/sec. As indicated by Table E-5, naturally occurring values of hydraulic conductivity span an extremely broad range—approximately 13 orders of magnitude.

  Hydraulic conductivity typically varies both spatially and directionally within an aquifer. The spatial variation, i.e., the variation of "K" from point to point within the aquifer, is referred to as "heterogeneity." The directional variation, which commonly occurs in layered sedimentary deposits, is referred to as "anisotropy." It is quite common during field studies to determine that "K" varies spatially by several orders of magnitude or more, even across very small sites, and that the ratio of horizontal to vertical hydraulic conductivity exceeds 10:1, i.e., an order of magnitude.

  For this reason, some hydrogeologists have attempted to quantify aquifer hydraulic conductivity using statistical distributions (Davis 1969). Although this subject is beyond the present scope, it does illustrate an important point. Due to the extremely wide range of values which hydraulic conductivity can assume, and considering its often large spatial and directional variation in the field, and also taking into account the difficulty in measuring this parameter (Section E.2.4.3.3), a high degree of accuracy in determining "K" and calculating groundwater flow rates based upon it should not be expected. In fact, order-of-magnitude estimates are probably the best which can be reasonably obtained. This means that we cannot hope to measure or quantify groundwater flow directly with the same degree of accuracy which can be obtained for total runoff (streamflow) or direct runoff (storm-related). The most reliable quantification of groundwater flow is based upon time- and area-integrated calculations in which groundwater flow from a watershed is calculated as the residual between measured streamflow and direct runoff.

TABLE E-5

TYPICAL RANGES OF HYDRAULIC CONDUCTIVITY (K) VALUES
(after Freeze and Cherry 1979)

Geologic Unit	Typical Range of Hydraulic Conductivity Values (cm/sec)
Unconsolidated	
Gravel	1.0E-01 to 1.0E + 02
Clean Sand	1.0E-03 to 1.0E + 00
Silt	1.0E-07 to 1.0E - 02
Unweathered Clay	1.0E-10 to 1.0E - 07
Consolidated Rock	
Karst Limestone	1.0E-04 to 1.0E + 00
Limestone	1.0E-07 to 1.0E - 03
Sandstone	1.0E-08 to 1.0E - 03
Shale	1.0E-11 to 1.0E - 07

- **Water table fluctuations:** The water table responds to a number of different hydrologic phenomena and is constantly in the process of adjusting toward a state of equilibrium. Several of the factors which influence shallow groundwater level fluctuations are:

  - **Precipitation:** Precipitation is the primary source of groundwater recharge. Therefore, variations in precipitation are closely correlated with water table fluctuations. However, because other factors besides total precipitation (e.g., storm pattern) affect the amount of water which infiltrates the ground surface and recharges groundwater, the correlation between precipitation and shallow groundwater levels is inexact and often apparent only on a long-term or seasonal basis. Nevertheless, although this correlation is imprecise and often delayed, it is nonetheless direct. In fact, if precipitation and groundwater recharge were to cease altogether, the water table throughout a watershed would eventually become flat, reaching the elevation of the permanent receiving surface water body into which the watershed discharged.

  - **Bank storage effects:** When water surface elevations in streams or lakes are high for extended periods of time, such as during spring thaw conditions, a significant volume of water may be discharged from these surface water bodies into their adjacent banks, causing a short-term to seasonal rise in adjacent shallow groundwater levels.

  - **Tidal effects:** Near oceans, the rise and fall of the tides has a corresponding influence on the adjacent water table, although this effect diminishes rapidly with increasing inland distance from the shoreline and with decreasing hydraulic conductivity of the aquifer. Like the tides themselves, this effect is typically diurnal.

- **Evapotranspiration:** Evapotranspiration can produce diurnal fluctuations of a shallow water table, provided that it occurs within the root zone of plants. Drawdown occurs during the day as a result of plant transpiration, and recovery occurs overnight when the plant stomata are closed. This phenomenon has been studied in connection with wetlands, where it has been used to estimate evapotranspiration rates based upon very precise monitoring of diurnal water table fluctuations (Heimburg 1984). Generally, for water tables occurring three or more feet below the ground surface, evapotranspiration is insignificant and has no effect upon water table fluctuations (Todd 1964).

- **Atmospheric pressure:** Short-term changes in atmospheric pressure can produce small variations in the water table, with water levels falling as air pressure increases. Except for the most sensitive monitoring studies, however, this effect is generally negligible.

- **Air entrapment during groundwater recharge:** During and immediately after heavy rainstorms, large rises have been noted in the water levels of shallow, unconfined aquifers. These short-term, anomalous increases in water level are caused by the entrapment of air, and the corresponding build-up of pressure, between the water table and a downward-advancing wetting front (Bianchi and Haskell 1966).

- **Human activities:** A variety of human activities can have long-term effects upon the depth and stability of the water table within an area. These activities include mine drainage, construction dewatering, industrial withdrawal, agricultural irrigation, and artificial recharge.

The net effect of the above factors is reflected in a continuously fluctuating water table, whose level can be measured using shallow wells or piezometers (Section E.2.4.3.3). Figure E-19 indicates a typical groundwater level monitoring record for an unconfined aquifer in Ohio (United States Geological Survey 1990). As indicated by the record, the water table at this location has varied over a range of approximately 10 feet, from depths of approximately 12 to 22 feet below the ground surface, during the 7-year operating history of the monitoring well. For reasons discussed subsequently, the range of water table fluctuation can be expected to decrease for progressively shallower water tables and at locations which are progressively closer to permanent surface water bodies (e.g., lakes or perennial streams).

- **Perched water tables:** The simplified groundwater flow system shown in Figure E-18, with a continuous vadose zone overlying the water table is common but not universal. In more complex geologic environments, layers of clays or silts (aquitards) may occur as interbedded lenses within the vadose zone, inhibiting the downward percolation of water to the water table. This situation, illustrated in Figure E-20, can result in a "perched water table," which is characterized by unsaturated conditions occurring between the perched and permanent water table. Low-permeability soils occurring at shallow depths can have a similar effect, with the added potential of causing water to pond at or near the ground surface. Because perched water tables are isolated from the permanent water table, they are continuously in a state of dissipation due to the effect of downward hydraulic gradients, which produce downward water flow—albeit slowly—through the underlying confining layer. Perched water tables are supported entirely by precipitation and resulting groundwater recharge. They are, therefore, subject to the same wide variations as precipitation (Section E.2.2) and tend to be ephemeral and unstable over extended time periods.

- **Monitoring wells and piezometers**: Groundwater flow occurs in a direction from high to low fluid energy potential. This potential, consisting of both elevation and pressure components, is expressed in terms of hydraulic head (h). The distribution of hydraulic head within a groundwater flow system and, therefore, the direction of groundwater flow, is three-dimensional. This means that groundwater has both horizontal and vertical flow components. However, it is frequently assumed in groundwater studies that flow in unconfined aquifers is essentially horizontal, and that vertical flow components are negligible. This, the so-called "Dupuit-Forchheimer assumption," is reasonably accurate over the large part of most unconfined aquifers, provided that the slope of the water table is small and the depth of the aquifer is relatively shallow. In Figure E-18, it applies throughout those areas where equipotential lines (i.e., lines of equal hydraulic head) are essentially vertical. In such areas, such as at monitoring well location MW-1 in Figure E-18, the hydraulic head measured at any vertical point would be essentially the same, and equal to the water table elevation at that location. However, at other locations, such as in the vicinity of permanent surface water bodies, there may be significant vertical components within the groundwater flow field. At location MW-2 in Figure E-18, for example, the hydraulic head measured at vertical point B is greater than at point A. This produces an upward vertical groundwater flow component at this location, with resulting groundwater discharge into the adjacent perennial stream.

  Hydraulic head within an aquifer may be measured by the use of monitoring wells or their simpler equivalent—piezometers. Figure E-21 indicates a typical construction detail for a groundwater monitoring well. Such wells can be used not only to measure hydraulic head but also to collect groundwater samples for chemical analysis and to perform in-situ hydrologic testing (e.g., slug testing for the field determination of hydraulic conductivity). The principal components of a groundwater monitoring well are:

  - A solid casing or "riser" which extends from the ground surface down to the depth at which monitoring is required;
  - A perforated or slotted well screen attached to the riser which allows the inflow of groundwater over the selected monitoring depth interval;
  - A filter pack of granular material placed outside the well screen to allow a free flow of groundwater into the well without permitting the entry of fine particles from the aquifer which could otherwise clog the well;
  - A bentonite seal above the filter pack to isolate the monitoring zone;
  - A cement-bentonite mixture above the seal to provide support for the well casing; and
  - A "stick-up" or well-head protector to allow access for monitoring and to secure the well.

  Monitoring wells may be constructed using a variety of materials (e.g., polyvinylchloride, stainless steel), with material choice depending upon the function of the well. The typical size range for groundwater monitoring wells is from 2 to 6 inches in diameter. A more complete discussion of their design and installation may be found in Driscoll (1986), Walton (1970) and United States Environmental Protection Agency (1986).

A piezometer is a simplified monitoring well, whose normal purpose is limited to the measurement of hydraulic head. Piezometers are typically smaller than monitoring wells (one inch or less in diameter). They are often installed without the use of drilling rigs, and sometimes without all of the design features associated with monitoring wells (e.g., filter packs). A piezometer must be sealed along its length, open to the atmosphere at its top, and open to the aquifer at its base. (The measurement point in a piezometer is always the base, not the level to which water rises within the casing.) A variety of intakes and design methods are available, including slotted pipe, driven well points, etc. For wetland studies, piezometers are typically hand-driven or installed using hand augers. This is possible because, for most wetland replacement projects, the water table is shallow and easily reachable by hand installation methods. A number of piezometer systems have been developed and employed by wetland researchers, including some with high sensitivity and continuous recording capability (Hemond 1982).

- **Groundwater recharge and discharge areas:** Groundwater replenishment does not occur uniformly across a watershed. It is concentrated in "recharge areas," which commonly (though not always) occur at relative topographic highlands. In recharge areas, there is a downward component to groundwater flow. Freeze and Cherry (1979) define recharge area as "that portion of the drainage basin in which the net saturated flow of groundwater is directed away from the water table." On the other hand, in "discharge areas," there is a net upward component to groundwater flow, as groundwater originating in upland recharge areas discharges as base flow into streams or seepage into wetlands, lakes, reservoirs, etc. Freeze and Cherry (1979) define discharge area as "that portion of the drainage basin in which the net saturated flow of groundwater is directed toward the water table." Recharge and discharge areas are shown schematically in Figure E-18. Although this diagram is representative of many shallow groundwater flow systems, it does not reflect the infinite variety of possible flow scenarios, which are controlled primarily by watershed topography and geology. Detailed discussions of this subject are presented in Freeze and Witherspoon (1967) and Winter (1988).

  Wetlands occur primarily in low-lying, discharge areas of a watershed. However, this is not always the case. In some upland areas, such as the prairie pothole region of the glaciated north-central United States, wetlands may occur in locations where groundwater recharge predominates for at least part of the year. Meyboom (1966) has studied such wetlands and found that the temporary ponds created by spring runoff may produce depression-focused groundwater recharge, which exceeds the reversed-flow groundwater discharge occurring in such potholes during the summer months.

- **Gaining versus losing streams:** A stream or other surface water body is referred to as "gaining" (or "effluent") when groundwater discharges into it. A "losing" (or "influent") stream, on the other hand, discharges into the groundwater flow system. The stream and lake shown in Figure E-18 are gaining, as indicated by the groundwater flow lines, and by the fact that their surface water elevations are lower than the adjacent water table. There is an obvious relationship between gaining/losing conditions and groundwater discharge/recharge areas. Permanent surface water bodies are typically gaining and tend to occur in topographically low, groundwater discharge areas. There are several conditions, however, under which streams or other surface water bodies may be naturally losing. These include: (1) intermittent surface waters which go dry during a part of the year (e.g., streams in arid climates, prairie potholes); and (2) perennial streams during flooding conditions when a portion of their flow is lost as bank storage. Winter (1976) provides a detailed, quantitative description of the interaction between groundwater and lakes.

With the exception of upland basins, such as prairie potholes, wetlands are usually gaining in nature (Kusler 1987 and Johnson 1987). They occur primarily in groundwater discharge areas. However, when groundwater levels fall, wetlands may temporarily lose water to the groundwater flow system and go dry on an intermittent or seasonal basis. Again, however, this applies primarily to upland basin wetlands. Those located adjacent to perennial surface water bodies typically receive an inflow of groundwater on an almost year-round basis.

- **Groundwatershed areas:** From a surface drainage standpoint, a watershed may be defined as the area contained within a drainage divide which contributes surface runoff to a selected measurement point. It is delineated by ground surface topography. Likewise, a groundwatershed may be defined as the area contained within a groundwater divide which contributes groundwater flow to a selected measurement point. Groundwater divides and surface drainage divides usually coincide approximately, especially in the case of shallow, unconfined aquifers. (This is roughly equivalent to the previously-stated generalization that the water table is usually a subdued reflection of surface topography.) Although always a reasonable first estimate, there are limitations to this assumption, as discussed below.

Toth (1963) has suggested that groundwater flow systems may be categorized as local, intermediate, or regional. The meaning of these terms is schematically illustrated on Figure E-22. As indicated by this figure, the groundwatershed contributing to a wetland may not, in all cases, be identical to the surface watershed area. Consider the two potential wetland locations shown as "A" and "B" on Figure E-22. Both of these locations are in groundwater discharge areas potentially capable of supporting a wetland. At location "A," the area contributing groundwater flow to the wetland is less than the surface watershed area; groundwater recharge on the left and right sides of this area leaves the local flow system in which the wetland is located to become part of the intermediate and/or regional flow systems. On the other hand, at location "B," the area contributing groundwater flow to the wetland is greater than the surface watershed area, since groundwater is discharged not only from the local flow system but also from the intermediate flow system originating outside this area.

The actual determination of contributing groundwatershed areas in a case such as that above is very difficult. It requires regional groundwater flow monitoring and analysis. Fortunately, such analysis is seldom necessary or justified for wetland replacement projects. In areas where the thickness of an unconfined aquifer is not too great, or where there is pronounced local relief (e.g., in hummocky terrains which are typical in the Eastern United States), only local groundwater flow systems will usually develop. In such situations, the assumption of approximate equivalence between surface watershed and groundwatershed areas is valid. Furthermore, even where there is some loss or gain of groundwater from intermediate or regional groundwater flow systems outside the surface drainage area, its effect would often be relatively minor within the context and accuracy of the overall hydrologic design. Therefore, the assumption that surface watershed and groundwatershed areas are equal is usually justified, and practically necessary, for most wetland replacement projects.

E.2.4.3.2 Groundwater Hydraulics: Although the subject of groundwater hydraulics is beyond the scope of this appendix, three of the more important and useful relationships governing groundwater flow are briefly discussed below.

- **Darcy's Law:** Darcy's Law is the empirical foundation upon which all quantitative analyses of fluid flow through porous media are based. The Law is expressed by the following equation:

$$Q = -KiA \qquad [2.7]$$

where, Q = groundwater flow rate [L**3/T]
K = hydraulic conductivity [L/T]
i = hydraulic gradient [L/L]
A = area of flow [L**2]

In this equation, hydraulic conductivity (K) is, as previously described, a function of both groundwater and the aquifer itself. Hydraulic gradient (i) is equal to the change in hydraulic head per unit length of groundwater flow (i.e., i = dh/dl). Because this hydraulic gradient can have components in all three dimensions, Darcy's Law can be considered a vector relationship describing three-dimensional groundwater flow. The negative sign before the right-hand side of Equation 2.7 indicates that groundwater flow always occurs in a direction of decreasing hydraulic head (i.e., from high to low "h"). Further, detailed discussion of this very important groundwater flow equation may be found in Freeze and Cherry (1979) and Fetter (1980).

- **Laplace Equation:** Besides Darcy's Law, a second basic groundwater flow relationship is the continuity equation, which states that the amount of groundwater flowing into any control volume must exactly equal the amount flowing out, under steady-state conditions (i.e., not varying with time). Combination of Darcy's Law and the continuity equation yields an important second-order differential equation, known as Laplace's Equation. Under the simplifying assumptions of groundwater flow through a homogeneous, isotropic aquifer under steady-state conditions, Laplace's Equation is expressed as:

$$\partial^2 h/\partial x^2 + \partial^2 h/\partial y^2 + \partial^2 h/\partial z^2 = 0 \qquad [2.8]$$

where, h = hydraulic head [L]

Laplace's Equation may be solved for known or assumed boundary conditions, such as constant head along a stream or wetland bounding an aquifer flow system, or no flow beneath a perennial stream acting as a groundwater divide. Although analytical solutions are possible in some relatively simple cases, the equation is most often solved numerically by groundwater computer flow modeling.

- **Dupuit-Forchheimer Relationship:** The Laplace Equation can be simplified for flow through an unconfined (water table) aquifer by assuming that: (1) groundwater flow is horizontal; and (2) the hydraulic gradient does not vary with depth and is equal to the slope of the water table. These so-called Dupuit-Forchheimer assumptions essentially involve neglecting the vertical components of groundwater flow and thereby reducingthe flow system analysis from three to two dimensions, as indicated by the following reduced and simplified version of the Laplace Equation:

$$\partial^2(h^2)/\partial x^2 + \partial^2(h^2)/\partial y^2 = 0 \qquad [2.9]$$

For the even more simplified case of cross-sectional flow analysis (i.e., ignoring the dimension "into the paper"), this equation can be further reduced to:

$$q = K/2L\ (hc^{**}2 - ho^{**}2) \qquad [2.10]$$

where, q = groundwater flow per unit strip width [L**2/T]
K = hydraulic conductivity [L/T]
ho,hc,L = lengths [L] as indicated on Figure E-23

Equation 2.10 describes a parabola-shaped water table, whose significance is further discussed in a later section of this appendix.

E.2.4.3.3 Groundwater Flow Evaluation: Historical groundwater flow from a gaged watershed can be calculated using a continuous streamflow hydrograph at the gaging station. The calculation involves:

- Selecting a time interval
- Separating base flow from direct runoff during all storm events which occurred during the interval (Figure E-15); and
- Integrating the resulting base-flow-only hydrograph over the time interval. This procedure provides an approximation of the total historical groundwater flow which occurred during the selected time interval at the particular gaging station.

Historical data such as these, for different time intervals, can be used to perform statistical frequency analyses of groundwater flow at the gaging station. Likewise, similar analyses can be performed for other gaged watersheds in the vicinity and the results regionalized to ungaged watersheds, including potential wetland replacement sites, by statistical methods such as those described in Beard (1962), United States Army Corps of Engineers (1975), and Yevdjevich (1964). Although such statistical analyses are fairly straightforward, they are also very laborious and, depending upon the adequacy of the historical data base and the degree of required extrapolation, subject to potentially significant errors.

Another approach to the estimation of groundwater flow is through the use of climatic water budgets, as proposed by Thomwaite and Mather (1955) and refined by Mather (1981). This approach, typically applied as a monthly water budget, involves the following basic steps:

- Calculation of monthly potential evapotranspiration by empirical equations or evaporation pan studies;
- Calculation of monthly direct runoff from historical precipitation using the SCS method (Section E.2.4.2.2), applied to actual daily precipitation totals during the month;
- Calculation of monthly actual evapotranspiration based upon potential evapotranspiration and calculated soil moisture storage; and
- Calculation of monthly groundwater flow as precipitation, minus direct runoff, minus actual evapotranspiration.

In reality, groundwater passes much more slowly through a watershed than does direct runoff. To account for this, a "lag" factor is typically assumed for most climatic water budget analyses. For example, Mather (1981) assumes that, for small watersheds in his New Jersey study, 25 percent of available groundwater surplus each month actually leaves the watershed as a component of total streamflow, while the remaining 75 percent is carried over and added to groundwater surplus available for groundwater flow the next month.

In addition to the above calculative approaches for estimating groundwater flow, there are several available methods for either measuring it directly or else measuring its controlling components and then calculating groundwater flow from these components. The following discussion briefly describes two of these methods.

- **Flow net analysis using Darcy's Law:** A flow net is a graphical depiction of intersecting groundwater flow lines and equipotential lines (i.e., lines of equal hydraulic head), as indicated by Figure E-18. The construction of a flow net requires a reasonable understanding of the three-dimensional distribution of hydraulic head (h) throughout an aquifer. Monitoring wells or piezometers are used to evaluate this head distribution. A typical groundwater monitoring study for this purpose involves the installation of a spatial array of wells or piezometers, as well as a number of vertical well/piezometer "nests" (i.e., co-located wells/piezometers monitoring hydraulic head at different depths.) The need for nested wells or piezometers is especially important near surface water bodies, such as wetlands, where there may be a substantial vertical component to groundwater flow. Given the distribution of hydraulic head throughout an aquifer, the flow net can be constructed, though to do so is somewhat of an art. The procedures and rules for flow net construction are contained in a number of texts on groundwater hydrology. One of the most complete and thorough presentations of this subject is found in: *Seepage, Drainage, and Flow Nets* (Cedergren 1977).

  With a flow net, Darcy's Law (Eq. 2.7) can be applied directly to calculate groundwater flow through any section of an aquifer or entering/leaving any control volume within the aquifer (e.g., a wetland or lake). Application of Eq. 2.7 does require, however, an independent evaluation of the aquifer's hydraulic conductivity (K) or hydraulic conductivity distribution. As discussed previously, accurate representation of this parameter is very difficult, due to its wide range of values and its typical spatial and directional variability within an aquifer. Hydraulic conductivity may be measured either in the laboratory or in the field. Laboratory determinations are performed using a variety of testing apparatus, including fixed- or falling-head permeameters, triaxial testing machines, and consolidation testing equipment. In general, laboratory measurements of hydraulic conductivity produce values which are significantly lower—typically by an order of magnitude or more—than those obtained by field measurements.

  Field evaluation of hydraulic conductivity is usually accomplished either by slug or pumping tests. The former, which can be accomplished using a single monitoring well, require that a slug of water or a solid object be suddenly injected or removed from a well, and the water level response be measured immediately thereafter. This response time can be used to calculate hydraulic conductivity of the aquifer material immediately around the well screen. A somewhat broader view of aquifer hydraulic conductivity can be obtained by pumping tests, though at a correspondingly higher price. A pumping test requires one pumping well and several nearby piezometers in which water level response within the aquifer is measured as pumping proceeds. As in the case of slug testing, there are various hydraulic formulas which can be used to calculate the aquifer's hydraulic conductivity based upon the noted response in the observation piezometers. A detailed presentation of laboratory hydraulic conductivity testing may be found in Lambe (1951); field testing methods and data interpretation are addressed in Walton (1970) and Driscoll (1986).

- **Seepage meters:** Lee (1977) initially described a very simple, low-cost method for directly measuring the seepage of groundwater into a surface water body. This method, which can also be used to estimate seepage into the groundwater system in the case of a losing stream or lake, involves the placement of a cylinder (typically half of a 55-gallon drum) directly on the bed of the surface water body. The cylinder, which is vented to a deflated plastic bag, is advanced by hand slowly into the bottom sediments until its top is several centimeters above the sediment surface. The amount of water seeping into the plastic bag over a given period of time indicates the seepage flux and also allows the collection of a sample for laboratory analysis, if desired.

  One advantage of the seepage meter is that it measures groundwater flow rate directly and does not require the estimation of hydraulic conductivity or hydraulic head distribution within the adjacent aquifer. For this reason, however, the meter's primary use is for the monitoring and evaluation of groundwater flow into existing surface water bodies, rather than for the prediction or estimation of groundwater flow at potential replacement sites. The meter has been used in a number of studies involving the interaction between groundwater and streams, lakes, and wetlands. In general, it has been found to work quite satisfactorily for surface water bodies whose beds consist of moderate- to coarse-grained sediments, but not very well for fine-grained beds.

E.2.5 WATER BALANCE PRINCIPLES

For any fixed volume in space, referred to as a "control volume," the law of mass conservation requires that, for an incompressible fluid during a given period of time, the inflow volume minus the outflow volume is equal to the change in storage, or:

$$I - O = dS \qquad [2.11]$$

where, I = inflow [L**3]
O = outflow [L**3]
dS = change in storage [L**3]

This is the basic hydrologic equation governing all water balance analyses. The components which make up I, O, and dS will vary, depending upon the choice of control volume. The following are some examples of water balance analyses for different control volumes:

- **Earth's atmosphere:** If the earth's atmosphere is taken as a control volume, inflow is equal to evapotranspiration, and outflow is equal to precipitation. On a global basis, the average annual precipitation for the entire earth, and therefore the average annual evapotranspiration, is 34 inches per year (Chow 1964).

- **Continental United States:** When regarding the continental United States as a control volume (i.e., its lithospheric surface), and ignoring the relatively insignificant water transfers across national borders, inflow is equal to precipitation (30 inches per year, average), and outflow is equal to evapotranspiration (21.5 inches per year) plus total runoff or streamflow (8.5 inches per year).

- **Territorial units:** Water balances are occasionally performed for separate territorial units. For example, the Ohio division of the United States Geological Survey (1990) has estimated the following water balance for the State of Ohio: average annual precipitation is approximately 38 inches state-wide; of this, approximately 10 inches runs off directly, 26 inches is evapotranspired or lost by consumptive use, and 2 inches discharges to streams as groundwater flow. The evapotranspiration/ consumptive use figure includes approximately 2 inches which is retained at the surface, 20 inches which is "lost" after infiltrating and entering the vadose zone, and 4 inches which is "lost" after reaching the water table but before discharging as streamflow.

- **Hydrologic units:** Water balance analyses may be performed for hydrologic units, including watersheds, lakes, and wetlands. The subject of wetland water balance studies is addressed further in Section E.3.3 of this appendix.

Despite the fact that water balance analyses are unique and highly varied, there are several generalizations which apply to all:

- Although Equation 2.11 theoretically applies to any control volume, not all water balance studies are meaningful. If a control volume or unit is selected in such a manner that its boundaries have no physical significance, then cross-boundary transfer terms which are difficult or impossible to measure may dominate the water balance. Likewise, regardless of boundaries, a water balance analysis will not provide meaningful results if its component inflow, outflow, and storage terms cannot be measured within reasonable limits of accuracy.

- In general, the accuracy of most hydrologic water balance studies increases for longer periods of time, since storage changes (e.g., groundwater level fluctuations) tend to even out over time and statistical anomalies tend to balance and offset one another.

- The accuracy of water balance analyses also generally increases with larger control volumes, since the effect of non-quantifiable cross-boundary transfer terms become proportionally less significant with increasing area.

LIMITATIONS OF WATER BALANCE STUDIES

If a control volume or unit is selected in such a manner that its boundaries have no physical significance, then cross-boundary transfer terms which are difficult or impossible to measure may dominate the water balance. Likewise, regardless of boundaries, a water balance analysis will not provide meaningful results if its component inflow, outflow, and storage terms cannot be measured within reasonable limits of accuracy.

E.2.6 SPECIAL TOPICS

E.2.6.1 Low Flow and Drought

The term "drought" refers to a period of time when there is a lack of rainfall so severe as to adversely affect the normal plant and animal life and/or the human activities of a place. This term is distinct from "aridity," which refers to the normal dryness of a place having very low average annual rainfall. Drought conditions obviously vary from location to location, depending upon the normal or average amounts of rainfall which occur there. For example, as indicated by Figure E-4, 20 inches of annual rainfall would constitute extreme drought conditions throughout most of the Eastern United States but would be an extremely wet year throughout most of the West.

Droughts can be expressed in terms of several water-related deficiencies, including: reduced precipitation, reduced streamflow (total runoff), lowered groundwater levels, and reduced soil moisture. All of these deficiencies are characteristic of droughts and often occur simultaneously. The two for which data are most readily available are reduced precipitation and reduced streamflow. Although a lack of rainfall during drought conditions is directly correlated with reduced streamflow, the percentage deviation from normal conditions is typically greater for streamflow than for precipitation (Hudson and Hazen 1964). The reason for this is that actual evapotranspiration (ET), the difference between watershed precipitation and streamflow, is a relatively stable climatic factor. During droughts, evapotranspiration needs are satisfied first, prior to direct runoff or groundwater flow. The rate of transpiration by plants and the overall rate of evaporation from soil and water surfaces increase during drought conditions, tending to offset the reduced soil moisture available for ET. The following simplified example, which assumes the same actual ET during a normal and dry year, indicates the relative percentage deviations of precipitation and streamflow:

	Normal Year	Dry Year	Deviation
Precipitation	40 in.	30 in.	-25%
Actual ET	24 in.	24 in.	0
Streamflow	16 in.	6 in.	-63%

RELATIONSHIPS IN REPLACEMENT DESIGN FOR BASIN WETLANDS

Since streamflow, or total runoff, is the component of the hydrologic cycle which ultimately supplies water for lakes, reservoirs, and wetlands, the relationship among precipitation, evapotranspiration, and streamflow is potentially significant for wetland replacement design of basin wetlands.

Since streamflow, or total runoff, is the component of the hydrologic cycle which ultimately supplies water for lakes, reservoirs, and wetlands, the above relationship is potentially significant for wetland replacement design of basin wetlands. It demonstrates the relatively high variability of total runoff during drought conditions, which directly affects the supply and level of water available to sustain wetlands during these periods. In other words, wetlands are very sensitive to droughts, although it must also be recognized that many wetland types can withstand periods of drought. Depending on the specific wetland replacement design, supplemental sources of water may be needed during the establishment period until the site hydrology has stabilized.

Drought conditions depend not only upon the magnitude of rainfall deficiency but also upon its duration. For gaged watersheds, streamflow records may be used for statistical analysis to develop discharge-duration-frequency curves for low-flow conditions. A typical format for such a curve is shown in Figure E-24. From this figure, it can be seen that for any selected duration (e.g., 30 days) average stream discharge for that duration is less for droughts with lower probability of occurrence, i.e., higher recurrence interval. (Probability, p, is equal to the inverse of recurrence interval, Tr, as $p = 1/Tr$.) The figure also demonstrates that, for a given recurrence interval, shorter durations correspond with lower average stream discharges. In describing such statistical analyses of low-flow conditions, the term "7Q10" would be used to refer to a 7-day average discharge with a 10-year recurrence interval; "30Q2" refers to a 30-day, 2-year low-flow discharge, etc.

The severity of a drought, expressed in terms of streamflow, is dependent upon the size of the contributing watershed area. To illustrate this point, consider the following general relationship between stream discharge and watershed area:

$$Qu = mA^{n} \qquad [2.12]$$

where, Qu = unit stream discharge in cubic feet per second per square mile [cfsm]
m = watershed proportionality factor
A = watershed area
n = constant

In the above equation, the exponent "n" is a function of flow conditions, as follows:

- **Long-term average flow conditions: (n = 0)** - When considering long-term average streamflow, unit discharge is independent of drainage area. (Alternately stated, mean discharge is directly proportional to drainage area.) Since unit discharge [cfsm] can be converted directly to total runoff [in], this means that the long-term average total runoff from a relatively homogeneous watershed is independent of drainage area. For example, if the total runoff is calculated from several stream gages within a fairly homogeneous watershed to be 10 inches, this value can also be applied to estimate the long-term average total runoff from a small drainage basin within the watershed contributing to a proposed wetland replacement site.

- **Flood conditions: (n < 0)** - During flooding conditions, unit discharge increases with decreasing watershed size. For example, if n = -0.25, the unit discharge during flooding conditions would be increased by approximately 19 percent for a 50 percent reduction in watershed size. In other words, during flooding events, smaller drainage basins produce a relatively greater unit discharge (and total runoff) than do larger watersheds.

- **Drought conditions: (n > 0)** - During drought conditions, unit discharge decreases with decreasing watershed size. Low-flow studies of streams in Michigan (Velz and Gannon 1960) have indicated that for 7-day low streamflows the value of "n" was approximately 0.25; similar studies in Ohio (United States Geological Survey 1981) have indicated "n" values for 7-day low flows ranging from approximately 0.35 to 0.42. For a value of n = 0.25, the unit discharge during low-flow conditions would be reduced by approximately 16 percent for a 50 percent reduction in watershed area; if watershed area were reduced by a factor of 10, the unit discharge would be reduced by almost 50 percent. In other words, during drought conditions, smaller watersheds produce a relatively smaller unit discharge (or total runoff) than do larger watersheds. This relationship is an important consideration for wetland replacement design, since the water supply to, and water levels within, a wetland are a function of total runoff from the contributing watershed. It can be seen that beyond the overall sensitivity of wetlands to drought conditions those wetlands with small contributing drainage areas are statistically more prone to droughts, and therefore they are less stable during drought conditions than are wetlands served by larger watersheds.

E.2.6.2 Tidal Hydrology

Tides are very long waves caused by astronomical forces with the effects of meteorological conditions sometimes superimposed. Astronomical tides are due to the relative configuration of the earth-moon-sun system. Their daily occurrence can be predicted by tidal harmonic analysis to within an accuracy of approximately 0.1 foot over the period of an ensuing year (Chow 1964). Meteorological tides are due to forces such as strong winds and barometric pressure changes. They can be predicted only in the same statistical sense as other meteorological phenomena and are relatively insignificant over long periods of time in comparison with astronomical tides.

SEMIDIURNAL TIDES

During a single lunar day, the tides typically pass through two maxima and two minima. These are referred to as "semidiurnal tides," and are common throughout most of the United States.

- With increasing latitude, there is an increasing inequality between the magnitude of the two daily high tides and low tides.

- Tides with marked diurnal inequalities are referred to as "mixed tides." At northerly sites, this inequality can be so pronounced that the tides are predominantly diurnal in character, i.e., one high and one low tide per day.

The gravitational forces of the sun and the moon are collectively responsible for the earth's tides. Although the sun's mass is much larger than the moon's, its gravitational effect upon earth tides is only about 46 percent as large as that produced by the moon, due to its much longer distance from the earth (Dean 1966). During a lunar month, the greatest tides occur during new moon and full moon, when the tide-producing effects of the sun and moon reinforce one another. These are referred to as "spring tides." Conversely, the minimum tides occur during the first and last quarter, when the effects of the sun and the moon are in opposition to one another. These are referred to as "neap tides." During a single lunar day, the tides typically pass through two maxima and two minima. These are referred to as "semidiurnal tides," and are common throughout most of the continental United States. However, with increasing latitude, there is an increasing inequality between the magnitude of the two daily high tides (i.e., between HHW=high high water and LHW=low high water), and between the magnitude of the two daily low tides (i.e., between HLW=high low water and LLW=low low water). Tides with marked diurnal inequalities are referred to as "mixed tides." At northerly sites (e.g., in Alaska), this inequality is so pronounced that the tides are predominantly diurnal in character, i.e., one high and one low tide per day. Estuaries may affect the amplitude of incident tidal waves in several ways, depending upon their geometry, depth, and shoreline conditions. In extreme cases, such as at the Bay of Fundy in Canada, tidal amplitudes may be greatly magnified as the tidal wave progresses inland. In other cases, the combined effects of sidewall reflection and boundary friction may diminish the tidal amplitude to zero in an inland direction. Ippen and Harleman (1966) discuss estuarine tidal dynamics at length.

In the United States, tidal amplitudes and currents are predicted and published on an annual basis (for the following year) by the National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA) in Silver Spring, Maryland (301-443-8060). This agency publishes the following separate products: East Coast Tide Tables, West Coast Tide Tables, Atlantic Tidal Currents, and Pacific Tidal Currents. The above publications provide tidal information for hundreds of primary and secondary United States tidal measurement stations. In addition, NOS offers a public-domain software package ("Tidal Prediction Package") for generating tide tables for other, unmonitored stations along the coasts.

E.2.6.3 Hydraulic Design Considerations

The term "hydraulics" refers to the science dealing with water at rest (hydrostatics) and in motion (hydrodynamics). Hydraulics may, in one sense, be regarded as a division of the broader science of hydrology. Whereas hydrology generally relates to the occurrence, properties, and movement of water on a large scale, hydraulics focuses upon the actual physical laws and processes governing its flow from one location to another. For example, the supply of water available to support a wetland is a subject of hydrology, while sizing of the wetland's outlet structures falls within the domain of hydraulics. There are numerous texts dealing with the subject of hydraulics in general and also with special hydraulic design applications such as flood routing, culvert design, etc. Several examples of comprehensive hydraulics texts are Chow (1959) and Morris (1963). The following discussion addresses only a few of the topics in this field, which have been selected because they are potentially relevant to wetland replacement design.

Estuaries may affect the amplitude of incident tidal waves in several ways, depending upon their geometry, depth, and shoreline conditions.

E.2.6.3.1 Uniform flow and the Manning Formula: Flow of water in an open channel is said to be uniform if the depth of flow is the same at every channel section (Chow 1959). A characteristic of uniform flow is that the slope of the water surface and the channel bottom are parallel. Although true uniform flow rarely exists in natural streams, it is usually assumed in hydraulic analysis of open-channel flow. This assumption produces results which, though approximate, offer a satisfactory solution in most practical situations.

Of the different methods available to describe uniform flow in open channels, the most widely used is the Manning Formula, which is stated as follows:

q = (1.49/n)(A)(R)**0.67(S)**0.5 [2.13]

where, q = uniform stream discharge [cfs]
n = roughness coefficient [dimensionless]
A = cross-sectional flow area [ft**2]
WP = wetted perimeter of flow [ft]
R = hydraulic radius = A/WP [ft]
S = channel slope [ft/ft]

U. S. TIDAL AMPLITUDE & CURRENT DATA

The National Ocean Service of the National Oceanic and Atmospheric Administration predicts and publishes annually tidal amplitudes and currents for the following year (Section F.2.6.2).

Table E-6 lists commonly used values for roughness coefficient (n). Channel slope (S) is usually calculated by field measurement or by reference to a topographical map. Area (A) and hydraulic radius (R) are geometric properties which depend upon channel shape and depth of flow. For a simple rectangular channel, Figure E-25 indicates how these terms are calculated and how the Manning Formula is applied to calculate the uniform stream discharge for a given flow depth (Yn). It should be noted that for a fixed channel geometry, slope, and roughness there is a singular relationship between uniform flow discharge (q) and uniform depth of flow (Yn).

DIFFERENCES BETWEEN HYDROLOGY AND HYDRAULICS

- Hydrology generally relates to the occurrence, properties, and movement of water on a large scale.
- Hydraulics focuses upon the actual physical laws and processes governing the flow of water from one location to another.

E.2.6.3.2 Hydraulic Control Structures: Wetland design may require the use of hydraulic structures to control the inflow or outflow of water from a wetland. Of the many such structures available, the following are among the most basic and widely used:

- **Open channels**, including ditches, gutters, flumes, etc., carry water with a free surface exposed to atmospheric pressure. For uniform flow conditions, the Manning Formula is used to quantify open-channel flow (Figure E-25).
- **Weirs** are overflow structures built across an open channel or at the outlet of a surface water body to measure or control the release of flow. The general formula for flow through a weir is:

$$q = cLh^{1.5}$$ [2.14]

where, q = weir discharge [cfs]
c = weir coefficient [dimensionless]
L = weir length [ft]
h = head on weir [ft]

The weir coefficient (c) depends upon the configuration and type of weir (e.g., broad- or sharp-crested). Coefficient values typically range from approximately 3.0 to 3.4. Weir length (L) and head (h) are as illustrated in Figure E-26.

- **Orifices** are submerged openings through which water flows. The general equation for flow through an orifice is:

$$q = cA(2gh)^{0.5}$$ [2.15]

where, q = orifice discharge [cfs]
c = orifice coefficient [dimensionless]
A = orifice area [ft**2}
g = gravity acceleration [32.2 ft/sec**2]
h = head on orifice [ft]

The orifice coefficient typically varies from approximately 0.60 to 0.65, depending upon the size and shape of the orifice opening. Other values required for the use of Equation 2.15 are illustrated in Figure E-26.

- **Culverts** are short, closed conduits through which water flows. Despite the apparent simplicity of these hydraulic structures, culvert flow is actually quite complex. At low flows, a culvert will flow partly full under uniform flow conditions, as described by the Manning Formula. As flow to a culvert increases, however, the inlet may become submerged and limit the hydraulic capacity of the culvert. As inlet submergence increases, the culvert's behavior approaches that of an orifice. On the other hand, if an elevated water surface (or "tailwater") occurs on the downstream end of the culvert, such as in the case of a culvert discharging into a flooding stream, water will essentially "back up" through the culvert. In this case, the culvert's capacity will be described by the so-called Bernoulli Equation, which is used in hydraulic engineering practice to analyze flow through pipe and storm drainage systems under surcharge conditions. Although further discussion of culvert hydraulics is beyond the present scope, a more complete description, with useable design nomographs, is included in United States Bureau of Public Roads (1965).

E.2.6.3.3 Backwater Analysis: During flooding conditions on natural streams, the previously stated assumptions regarding uniform flow are not satisfied. Flow depth varies along the channel, and the slope of the water surface and channel bottom diverge. When these deviations from uniform flow assumptions are not too abrupt, the flow is referred to as "gradually varied flow." Its analysis requires stepwise calculations in an upstream direction, proceeding from a known or calculated downstream starting water surface elevation (e.g., the elevation of a lake into which the stream flows). This procedure is described as a "backwater analysis." Although backwater analyses can be performed by hand calculation, the effort is tedious and time-consuming. More often, computer programs are used to solve the flooding profiles along stream channels using the procedures of backwater analysis. One of the most well-known and widely used of these is the "HEC-2 Water Surface Profiles" program by the United States Army Corps of Engineers (1976).

Although the subject of backwater analysis itself is not particularly relevant to wetland replacement design, one of its underlying principles is. In order to determine the surface water profile along a stream channel, it is necessary in backwater analysis to find a known and relatively independent downstream starting water surface elevation and then to work back upstream to calculate corresponding water surface elevations at higher locations throughout the channel system. So, too, for wetland hydrologic design for riverine wetlands, the estimation of water surface elevations and water surface elevation fluctuations (i.e., the hydroperiod) must normally proceed in an upgradient direction from a known and relatively independent (of the wetland) permanent surface water elevation. This subject is addressed further in the following sections of this appendix.

E.2.6.3.4 Flood Routing: Flood routing refers to the modification which a flood hydrograph undergoes as it passes through a stream channel reach or surface water body, such as a wetland. In this appendix, we are concerned primarily with the routing of flow through surface water bodies, which is sometimes referred to more specifically as "reservoir routing."

One of the functions of wetlands and reservoirs is the reduction and desynchronization of peak storm flow discharges by the temporary storage of direct runoff. An inflow hydrograph to a wetland typically has its peak discharge reduced in magnitude and delayed in time , as illustrated in Figure E-27. The physical process illustrated by this figure can be described as follows. As water begins flowing into the wetland, a portion of it is temporarily stored while the rest passes out through an outlet structure. As time progresses, the volume of temporary storage within the wetland increases, creating a rise in water surface elevation. With rising water surface elevation, the outflow discharge (which is typically a function of hydraulic head on the outlet structure) also increases. Point A on Figure E-27 represents the time and maximum rate of outflow from the wetland, as well as the time of maximum temporary water storage within. Beyond this time (i.e., to the right of Point A), the outflow rate from the wetland begins to decrease and the volume of temporary storage within the wetland is reduced.

From a design viewpoint, several important aspects of flood routing are illustrated by Figure E-27:

- The peak rate of outflow from a wetland (Point A) always occurs on the recession limb of the inflow hydrograph.

TABLE E-6

ROUGHNESS COEFFICIENT (n) FOR MANNING FORMULA
(after United States Army Corps of Engineers 1959)

Value of "n"	Channel Conditions
0.013	Typical reinforced concrete pipe.
0.016 - 0.017	Smoothest natural earth channels, free from growth, with straight alignment.
0.020	Smooth natural earth channels, free from growth, little curvature.
0.0225	Average, well-constructed, moderate-sized earth channels in good condition.
0.024	Typical corrugated metal pipe.
0.025	Small earth channels in good condition or large earth channels with some growth on banks or scattered cobbles in bed.
0.030	Earth channels with considerable growth. Natural streams with good alignment, fairly consistent section. Large floodway channels, well maintained.
0.035	Earth channels considerably covered with small growth. Cleared but not continuously maintained floodways.
0.040 - 0.050	Mountain streams in clean loose cobbles. Rivers with variable section and some vegetation growing in banks. Earth channels with thick aquatic growths.
0.060 - 0.075	Rivers with fairly straight alignment and cross section, badly obstructed by small trees, very little underbrush or aquatic growth.
0.100	Rivers with irregular alignment and cross section, moderately obstructed by small trees and underbrush. Rivers with fairly regular alignment and cross section, heavily obstructed by small trees and underbrush.
0.125	Rivers with irregular alignment and cross section, covered with growth of virgin timber and occasional dense patches of bushes and small trees, some logs and dead fallen trees.
0.150 - 0.200	Rivers with very irregular alignment and cross section, many roots, trees, bushes, large logs and other drift on bottom, trees continually falling into channel due to bank caving.

- The maximum volume of water temporarily stored within the wetland is indicated by the shaded area between the inflow and outflow hydrographs to the left of Point A. Note that the area under any hydrograph during a specific time interval represents the volume of water produced by that hydrograph during the time interval. The shaded area in Figure E-27 is consequently equal to the total volume of water flowing into the wetland basin up to the time of maximum temporary storage (Point A) minus the total volume of water flowing out of the wetland during that time period, or the maximum volume of temporary storage.

- Wetlands and flood control reservoirs can significantly influence the timing and peak rate of storm discharge but typically have little effect on the total volume of direct runoff produced during a storm. In other words, the total area under the inflow and outflow hydrographs in Figure E-27 are usually approximately equal.

WETLAND HYDROLOGIC DESIGN IN RIVERINE WETLANDS

For wetland hydrology design for riverine wetlands, the estimation of water surface elevations and water surface elevation fluctuations (i.e., the hydroperiod) must normally proceed in an upgradient direction from a known and relatively independent (of the wetland) permanent surface water elevation.

One of the functions of wetlands and reservoirs is the reduction and desynchronization of peak storm flow discharges by the temporary storage of direct runoff.

E.2.6.4 Hydrologic Models

A hydrologic model is simply a tool designed to represent a simplified version of a hydrologic process. In this sense, all of the relationships and equations presented previously in this appendix may be regarded as models. When solved directly using mathematical equations, they are classified as "analytical models." In reality, natural hydrologic systems are often too complex, require too limiting a set of simplifying assumptions, or involve too many repetitive steps, to solve practically by exact analytical methods. In such cases, the mathematical equations are usually solved by approximate numerical techniques. "Numerical models" involve discretization of the continuum which makes up the hydrologic system followed by repetitive, successive solution of simplifying equations applied to each of the discrete elements. Numerical models are almost always solved by the use of computer program codes.

There are thousands of numerical models available for different hydrological applications. A few of these have previously been described. These numerical models may be broadly categorized as follows:

- **Groundwater models:** Groundwater models are used to describe the physical flow of groundwater ("flow models") and/or the transport of contaminants through an aquifer ("transport models"). Wang and Anderson (1982) provide a simplified and understandable description of the process of groundwater modeling using finite difference and finite element methods. In addition, numerous texts are available describing and documenting the hundreds of specific groundwater models which have been developed during the past decade. The International Ground Water Modeling Center

(IGWMC) of the Colorado School of Mines (303/273-3103) monitors current developments in groundwater modeling and publishes a quarterly newsletter on the subject.

- **Surface water flow models:** Among the many numerical models which have been developed to describe various aspects of surface water flow, several of the more useful and widely applied are:
  - **HEC-1** (U.S. Army Corps of Engineers, Hydraulic Engineering Center): Computes and routes hydrographs through a watershed.
  - **HEC-2** (U.S. Army Corps of Engineers, Hydraulic Engineering Center): Computes flood water surface profiles throughout a channel system using backwater analysis methods.
  - **TR-20** (U.S. Soil Conservation Service): Computes direct runoff, develops runoff hydrographs, and routes hydrographs through a watershed.
  - **WSP2** (U.S. Soil Conservation Service): Computes flood water surface profiles through open channels.
- **Other models:** There are also a variety of special-application hydrologic models available such as the previously-mentioned "Tidal Prediction Package" by the National Ocean Service of the National Oceanic and Atmospheric Administration. Chu and Bower (1977) provide a summary of computer programs available for water resource applications.

E.2.6.5 Sources of Hydrologic Data

Because hydrologic processes are stochastic by nature, a considerable amount of data must be collected before they can be understood or accurately predicted. Since the acquisition of hydrologic data is typically expensive and time-consuming, a wetland replacement designer should always seek to identify and acquire existing information before deciding to undertake new data-collection activities. There are many types of hydrologic data available and a number of different agencies responsible for their collection, use and dissemination. Two useful sources of information concerning hydrologic data availability are the National Water Data Exchange and the Federal Highway Administration's Hydraulic Engineering Circular No. 19, *Hydrology* (1984). These two sources are briefly described in the following paragraphs.

The National Water Data Exchange (NAWDEX) is a national organization of water-related organizations whose primary objective is to assist users of water data in the identification, location, and acquisition of hydrologic data. The program is operated by the Water Resources Division of the United States Geological Survey in Reston, Virginia (703-648-5663). NAWDEX is not itself a repository of hydrologic data. Instead, it indexes the data held by its members and participants to provide a central source of water-data information available from a large number of organizations. This indexing takes two principal forms, which are themselves internally cross-referenced:

- *The Water Data Sources Directory* identifies and provides pertinent information concerning approximately 450 organizations providing hydrologic data; and
- *The Master Water Data Index* identifies and describes the types of water data which are available from these organizations at more than 450,000 sites nationwide.

Direct access to NAWDEX is available through a nationwide network of 75 Assistance Centers located in 45 states, the District of Columbia, and Puerto Rico.

The Federal Highway Administration's *Hydraulic Engineering Circular No. 19* (U.S. Federal Highway Administration 1984) includes, as Appendix C, a list of the major Federal agencies providing hydrologic data. This appendix also indicates the locations, addresses, and telephone numbers of the district and state offices of these agencies nationwide.

Of the various agencies and organizations providing hydrologic data which are potentially useful for wetland replacement design, the following are among the most important:

- **United States Geological Survey (USGS):** The USGS, a part of the U.S. Department of Interior, is the major source of streamflow data in the United States. This agency collects data at approximately 16,000 stream-gaging stations nationwide and compiles them in annual "Water Resources Data" reports, which are typically published by individual states. The USGS also maintains a large computerized data base for this information called the Water Data Storage and Retrieval System, or WATSTORE, which can be directly accessed through district USGS offices. In addition, USGS Water Resources Division staff routinely publish professional papers, articles, and other information offering interpretations of hydrologic data and reporting the results of related USGS investigations and activities.

- **National Weather Service (NWS):** The NWS, a part of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, is the primary source of precipitation and climatological data (including evaporation data) in the United States. The NWS makes daily weather-related measurements at approximately 20,000 locations nationwide. These data are processed and disseminated by the National Climatic Data Center (NCDC) of the Environmental Data and Information Service (EDIS), in Asheville, North Carolina. Data are published in the form of monthly "Climatological Data" reports, by individual states and localities, and are also summarized and statistically interpreted in numerous NCDC publications.

- **Corps of Engineers (COE):** The COE, a part of the U.S. Department of the Army, also collects hydrologic data, including streamflow records, lake and reservoir water levels, and other information related to COE projects and activities.

- **Soil Conservation Service (SCS):** The SCS, an agency within the U.S. Department of Agriculture, is responsible for the classification and mapping of soils across the country. SCS soil surveys have been prepared for most counties. This information is needed to perform hydrology calculations and to predict direct storm runoff using the SCS Method, which was described in Section E.2.4.2.2.

- **National Ocean Service (NOS):** The NOS, another agency within the National Oceanic and Atmospheric Administration, publishes annual projections of daily tides and tidal currents at stations located throughout U.S. coastal areas. This agency also produces other publications and information relating to tides and tidal currents, including a "Tidal Prediction Package" computer program which can be used to generate tide tables at unmonitored locations.

- **Environmental Protection Agency (EPA):** The United States EPA has access to data and information concerning environmental projects and activities throughout the country. For example, solid and hazardous waste sites (e.g., landfills) often require the collection of extensive localized hydrologic information such as groundwater levels, flow directions, and quality. Such data are available in reports published for or reviewed by the EPA.

- **Federal Emergency Management Agency (FEMA):** FEMA, an agency within the U.S. Department of Housing and Urban Development, is responsible for management of the National Flood Insurance Program. As part of this program, Flood Insurance Studies have been performed for most metropolitan areas within the United States. These studies include watershed hydrologic and stream hydraulic analyses related to flood flows including field data and measurements.

- **State and municipal agencies:** Many state and municipal agencies are involved in the collection of hydrologic data either on their own or in cooperation with one or more of the above federal agencies. For example, the Ohio Department of Natural Resources (ODNR) is responsible for the permitting and registering of groundwater wells and cooperates with the Ohio Division of the USGS in collecting groundwater level and groundwater quality information from these wells. Similar arrangements are common in other states and localities and can usually be ascertained by inquiry to the state or district office of the appropriate federal agency.

E.3 WETLAND HYDROLOGY

The basic hydrologic concepts discussed in the previous section of this appendix are fundamental to an understanding of wetland hydrology. Their direct application, however, is difficult for a number of reasons. Because wetlands typically involve a dynamic interaction between groundwater and surface water, their hydrology is more complex than that of either one individually. The study of wetlands from a hydrologic perspective is also complicated by the uniqueness of and extreme variation between different wetland types. In fact, this diversity is so great that it sometimes obscures the single unifying characteristic of virtually all wetlands—the presence of water at or near the ground surface. This section focuses upon those aspects of hydrology which are unique and important to wetlands. Its purpose is to provide the wetland replacement designer with a basic understanding of wetland hydrology and to form a conceptual foundation for the design process itself.

E.3.1 THE HYDROPERIOD

The water level occurring within a wetland represents the cumulative effect of all hydrologic inflows and outflows. It fluctuates continuously with time as the wetland responds to these changing inflows and outflows, always adjusting toward a condition of dynamic equilibrium. The term "hydroperiod" refers to the variation in wetland water level with time. Hydroperiod is the dominant hydrologic factor controlling the occurrence, distribution, and stability of wetlands. It serves as a "fingerprint" of individual wetlands and wetland types and is an important criterion in most wetland classification schemes, as discussed in the following section.

The hydroperiod of a wetland incorporates two time-related measures: duration and frequency of flooding. For some wetland types, such as tidal salt marshes, hydroperiod is very predictable. It consists primarily of a semidiurnal pattern of flood and ebb tides superimposed upon a bi-monthly pattern of spring and neap tides. At the opposite extreme are wetlands associated with upland drainage basins whose hydrology and hydroperiod are weather-controlled and which are, therefore, subject to significant seasonal and annual fluctuations in water level. The duration and frequency of flooding for these "basin" wetlands are often unpredictable and therefore may be unreliable, except in a statistical

WHAT IS THE HYDROPERIOD IN A WETLAND?

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sense. Figure E-28 indicates typical hydroperiods for some different types of wetlands.

It should be noted from Figure E-28 that hydroperiod can be represented by a continuous plot of water level versus time. Such a representation combines the dual hydroperiod elements of flood duration and flood frequency. In this context, "flood" refers to those time periods when the water level is above the ground surface. For wetland replacement projects, the concept of hydroperiod must consider both water surface and ground surface elevation, with water depth being the difference between the two. The ground surface elevation "half" of this equation may be manipulated by earthwork and grading activities at a proposed replacement site, providing that the groundwater does not fluctuate. Otherwise, from a practical standpoint, the "two halves" must be separated; otherwise the constructed wetland may drain dry due to seasonal lowering of the water table. It thus becomes critical during the siting and design process to understand the two halves. It may be necessary to seal the wetland basin to prevent this problem. When this occurs, the designer will usually be forced to rely totally on surface runoff and direct precipitation.

HYDROPERIODS OF SALT MARSHES & UPLAND DRAINAGE BASINS

- Salt marshes have a predictable hydroperiod that consists of a semidiurnal pattern of flood and ebb tides superimposed on a bi-monthly pattern of spring and neap tides.

- The hydrology and hydroperiod of upland drainage basins is weather-controlled. They are, therefore, subject to significant seasonal and annual fluctuations in water level.

For some wetland types, such as tidal salt marshes, hydroperiod is very predictable. At the opposite extreme are wetlands associated with upland drainage basins whose hydrology and hydroperiod are weather-controlled and which are, therefore, subject to significant seasonal and annual fluctuations in water level. The duration and frequency of flooding for these "basin" wetlands are often unpredictable and, therefore, may be unreliable, except in a statistical sense.

Water surface elevation cannot be controlled as easily, however. Although hydraulic structures can be used to limit water surface elevation on the "high side" (e.g., by setting the weir elevation on an overflow spillway), no such manipulation is possible for minimum water levels if the watershed supply is inadequate to maintain them. For this reason, the hydroperiod of a proposed wetland replacement site may be regarded as a partially controllable design parameter.

In some wetland literature, and in some non-tidal wetland classification systems, hydroperiod is expressed using the single measure of flood duration. In this context, hydroperiod refers to the total amount of time per year or during the growing season that a wetland is flooded, i.e., that water occurs at or above the ground surface (saturated or inundated). Descriptive terminology, such as "semipermanently" or "seasonally" flooded, is sometimes used in classification systems to describe the total hydroperiod duration; or the hydroperiod is occasionally expressed even more generally using terms such as "long" or "short." An example of a duration-based hydroperiod classification is found in the United States Army *Corps of Engineers Wetland Delineation Manual* (1987), which is discussed in the following section and which is the recommended classification system used in the *Guidelines*.

Among the different hydrologic factors affecting the success and stability of wetland replacement projects, hydroperiod during the growing season is the most important one. The individual hydrologic inputs and outputs which collectively determine the hydroperiod, and the relative balance between these components when applicable (e.g., the ratio of surface water to groundwater inflow), are also important, especially as they relate to the water quality and productivity of a wetland. However, even without a complete understanding of these component terms, wetlands can be successfully restored and created if their hydroperiods can be estimated with a reasonable degree of accuracy, and the stability of the groundwater elevations is understood. For this reason, the remainder of this appendix is focused upon those wetland hydrologic concepts which are directly related to the prediction of water levels and water level fluctuations —both prior to and after the implementation of a wetland replacement project.

E.3.2 HYDROLOGIC CLASSIFICATION SYSTEM

Since the early 1900s, many wetland classification systems have been proposed. Most are either based entirely upon hydrology or else include hydrology as a principal classification criterion. Because the wetland replacement process requires the identification and characterization of potential wetland sites in terms of their hydrologic setting (Section E.4), a few of the more recent and/or widely known wetland classification systems are discussed briefly below.

> **Although hydraulic structures can be used to limit water surface elevation on the "high side" (e.g., by setting the weir elevation on an overflow spillway), no such manipulation is possible for minimum water levels if the watershed supply is inadequate to maintain them. For this reason, the hydroperiod of a proposed wetland replacement site may be regarded as a partially controllable design parameter.**

E.3.2.1 The United States Fish and Wildlife Service

The Service (Cowardin et al. 1979) has developed a comprehensive wetland classification system, which is illustrated in Figure E-29. Under this system, wetlands are grouped in a hierarchical classification consisting of systems, subsystems, and classes. These are defined as follows:

- Systems are based upon geomorphologic location within a watershed, type of vegetation, extent of vegetative coverage, wetland size, and salinity;
- Subsystems are distinguished on the basis of hydroperiod and hydrologic energy environment;
- Classes are based upon general appearance, including substrate type or dominant vegetation.

E.3.2.2 The United States Army *Corps of Engineers Wetland Delineation Manual*

This manual (1987) classifies wetlands on the sole basis of hydroperiod duration, as indicated by Table E-7. This classification system is for non-tidal wetlands only. The "duration" shown on Table E-7 refers to the total length of time during the growing season when the wetland soil surface is flooded or saturated. This system forms the basis for the recommended approaches for establishing the replacement wetland hydroperiod and develops the landscape plan.

E.3.2.3 Novitzki's Proposed Classification

Novitzki (1978) has proposed a regional classification system for Wisconsin's wetlands which includes four classes:

- Surface water depression wetlands
- Surface water slope wetlands
- Groundwater depression wetlands
- Groundwater slope wetlands.

These classes are differentiated on the basis of landscape (topographic) position and the relationship between surface and groundwater levels at the site.

E.3.2.4 Brinson's Proposed Geomorphological Classification System

Brinson (1986) has proposed a geomorphological classification system by which wetlands are divided into three categories:

- Basin (or depressional) wetlands, which typically occur in headwater regions of a watershed and capture drainage from only relatively small, upland areas
- Riverine wetlands, which occur along various size streams and river channels within a watershed
- Fringe wetlands, which occur at the base of a watershed adjacent to large and permanent surface water bodies such as lakes, reservoirs, or estuaries.

The systems described above are just a few of the many which have been proposed for wetland classification. In general, such classifications may serve a variety of different purposes, including inventory, evaluation, and management of wetlands (Cowardin et al. 1979).

TABLE E-7

U.S. ARMY COE WETLAND CLASSIFICATION SYSTEM
(after United States Army Corps of Engineers 1987)

Zone	Name	Duration	Comments
I	Permanently inundated	100%	Inundation > 6.6 ft mean water depth
II	Semipermanently to nearly permanently inundated or saturated	> 75% - < 100%	Inundation defined as ≤ 6.6 ft mean water depth
III	Regularly inundated or saturated	> 25% - 75%	
IV	Seasonally inundated or saturated	> 12.5% - 25%	
V	Irregularly inundated or saturated	≥ 5% - 12.5%	Many areas having these hydrologic characteristics are not wetlands
VI	Intermittently or never inundated or saturated	< 5%	Areas with these hydrologic characteristics are not wetlands

For our present purpose, the goal of a hydrologic classification system is more limited. Wetland replacement design requires that the position of a potential replacement site be identified within the context of the overall hydrologic landscape. Such identification is necessary to establish the relationship between the wetland site and its supporting watershed and the interaction (if any) between the wetland and any associated, permanent surface water bodies in nearby proximity. For this purpose, the simple classification system proposed by Brinson (1986) is adequate. Table E-8 summarizes and expands upon this three-category classification system. Before discussing it, however, an important point should be made regarding wetland classification in general. All classification systems, even the most detailed, represent a compromise between:

- The important need to categorize wetlands for inventory, evaluation, and management purposes and
- The almost infinite variety of individual wetlands and the continuous gradation between wetland types.

E.3.2.5 The Hydrologic Design and Predicting Hydroperiod

The ultimate goal for replacement wetlands is to predict the hydroperiod, i.e., the depth and duration of inundation at the replacement site. Table E-7, which is cited above and used elsewhere within the *Guidelines*, is based directly upon the hydroperiod parameter and therefore represents the desired **end product** of the hydrologic design. Table E-8 provides a different but consistent classification system, which accounts also for the geomorphologic and hydrologic characteristics of the wetland and its supporting watershed (e.g., watershed position, associated permanent surface water body). The classification system in Table E-8 is used in the following discussion because it provides a foundation and framework for the hydrologic characterization and evaluation of wetlands, which end result is to identify the important hydroperiods in Table E-7. In other words, the functional relationship between the two supporting classification systems in Tables E-8 and E-7 is essentially one of process and end product, respectively. The general wetland classes in Table E-8 (e.g., basin wetlands) can, depending upon site-specific hydrologic circumstances, encompass the full range of wetland types indicated in Table E-7, i.e., "permanently inundated (Zone I)" to "intermittently or never inundated (Zone VI)."

Referring to Table E-8, several key points can be made regarding the hydrologic aspects of the three wetland classes:

- Basin wetlands may be the most difficult to design from a hydrologic standpoint. They are fed by relatively small drainage areas and often lack inflow from either surface water (direct runoff) or groundwater supply sources, sometimes from both. This results in less total supporting runoff for basin wetlands than for wetlands located at lower elevations within a watershed. Also, as discussed in Section E.2.6.1, these wetlands are more prone to drought conditions than are riverine or fringe wetlands since their smaller watersheds produce a relatively smaller unit discharge (cubic feet per second per square mile, cfsm) during droughts than do larger watersheds. Due to the above considerations, the hydroperiod of basin wetlands is generally both more variable and less predictable than that of riverine or fringe wetlands.

- Riverine wetlands occupy watershed positions which are topographically and geomorphologically intermediate between basin and fringe wetlands. They are correspondingly intermediate in terms of contributing watershed area and hydroperiod predictability (Table E-8). Riverine wetlands lie adjacent to perennial streams which, in most cases, exert a controlling and stabilizing influence upon their hydroperiods. Unlike basin wetlands, whose hydroperiod is a function of the inflows from relatively small contributing drainage areas, riverine wetlands have hydroperiods which are controlled largely by the water levels within their adjacent streams. These streams are, in turn, supported by much larger watersheds than the overland area draining directly into the wetland, and are consequently less prone to the vicissitudes of climate and weather. This is not to say that the water levels occurring in natural stream and river channels are either constant or entirely predictable. They are not. However, in comparison with the hydroperiod of basin wetlands, the water levels of perennial streams—and the corresponding hydroperiod of riverine wetlands—are **relatively** stable and predictable. There are several reasons for this:

    - The larger watershed areas contributing to perennial streams, especially regional watercourses with higher stream order, have a dampening effect on both high (flood) and low (drought) flow conditions (discussed in Section E.2.6.1). Thus, the water levels associated with them tend to be more stable than those of smaller, upland areas or intermittent streams.

    - Many perennial streams either have stream gaging data available or have been studied to some degree as part of the national Flood Insurance Program. The resulting data and information are sufficient, in many cases, to calculate directly water levels on a statistical basis or at least to extrapolate them. In such cases, the corresponding hydroperiod in adjacent riverine wetlands can be estimated from these statistical analyses.

    - Over extended time periods, the water levels in perennial streams generally fluctuate less with changing total watershed runoff than do the levels of the contiguous water tables discharging into the streams. Water table fluctuations become progressively greater with increasing distance from the stream, a relationship controlled by groundwater and surface water hydraulics, as demonstrated by the example that follows below (Example A, A Comparison of Water-Level Fluctuations in Two Perennial Streams). Now suppose that, for another extended period of time, precipitation across the watershed is significantly below average, such that base flow in the stream and the corresponding groundwater flow in the strip are reduced to one-half their previous values, or 63.5 cfs and 1.32 cfd, respectively. Using the same formulas, assumptions and input values as above, a new water surface profile can be calculated for this reduced-flow condition. This is represented by the lower profile and the second column of accompanying values in Figure E-31.

As previous discussion in Section E.2 suggests, this example contains a number of very broad assumptions and simplifications. Its importance is not the specific numerical results which it yields for groundwater and surface water levels but, rather, the observed relationship between these two in terms of their relative fluctuations under different long-term average runoff conditions. As seen from Figure E-31, a uniform, basin-wide change in groundwater flow and streamflow within a watershed typically produces more pronounced effects on water table elevations than on surface water elevations in perennial streams. Moreover, groundwater levels are subject to progressively greater fluctuations as their distance from permanent surface water bodies increases. For this reason, over extended time periods, groundwater-fed wetlands lying near or adjacent to perennial surface water bodies (e.g., riverine and fringe wetlands) can be expected to show considerably less variation in water levels than those lying further inland.

It should be carefully noted that this example pertains to long-term average flow conditions. Over the short term, particularly during storms and related flooding events, the water levels in perennial streams and their adjacent wetlands will rise and fall faster than the groundwater table. During these high-water periods, streams may temporarily lose water to the surrounding groundwater as a result of bank storage effects (Section E.2.4.3.1). Since water flows much more slowly through the ground than it does overland, such effects are dampened while moving inland away from the stream. It should also be noted that because groundwater levels respond much more slowly to changing stimuli than do surface water levels the equilibrium water profiles shown in Figure E-31 may take a long time to develop—or they may never "catch up" with the more rapidly changing surface water levels.

- As indicated by Table E-8, fringe wetlands lie adjacent to surface water bodies which generally have the largest contributing watershed areas and correspondingly produce the most predictable wetland hydroperiods of the three wetland classes. For example, ocean water levels are controlled by astronomical forces and runoff from entire continental land masses. The hydroperiods of adjacent tidal wetlands are almost entirely predictable, provided that open hydraulic contact is maintained between the ocean and the adjacent wetland. Even those fringe wetlands which lie adjacent to surface water bodies supported by smaller watershed areas, such as lakes or reservoirs, generally have relatively stable and predictable hydroperiods.

A COMPARISON OF WATER-LEVEL FLUCTUATIONS IN TWO PERENNIAL STREAMS

EXAMPLE A: Consider the two locations, A and B, shown on Figure E-30. Location A is on a watercourse with an upstream drainage area of approximately 150 square miles. Location B is approximately 1,000 feet distant from Location A, on the drainage divide of a small overland tributary area which drains directly to the watercourse. From stream gages located within this and other nearby and similar watersheds (e.g., Figure E-13), the long-term average total runoff (or streamflow) from this watershed is estimated to be approximately 11.5 inches per year. As discussed in Section E.2.6.1, this long-term average streamflow can be applied to the entire watershed and also to smaller subareas within the watershed. By simple conversion, a total runoff of 11.5 inches per year is equal to a unit discharge (Qu) of 0.85 cubic feet per second per square mile (cfsm). This unit discharge can be directly applied to the total watershed area above Location A (150 square miles) to determine that the long-term average streamflow at Location A is approximately 127 cubic feet per second (cfs). Also, it can be applied as a rough estimate to the overland drainage area between Locations B and A. Considering an arbitrary one-foot-wide surface from Location B to Location A, and applying the same unit discharge of 0.85 cfsm, or 11.5 inches, the average total runoff from this strip area can be calculated (after appropriate unit conversion) as approximately 2.63 cubic feet per day (cfd). Assume, for illustrative purposes only, that these long-term average flows from the watershed and upland strip occur for some period of time, sufficient to allow equilibrium conditions, as base flow in the stream and groundwater flow in the strip draining to the stream. Then, using the Manning Formula (Equation 2.13), and the measured or estimated channel properties shown on Figure E-30, the normal flow depth within the channel can be calculated as 1.33 feet. Likewise, using the Dupuit-Forchheimer assumptions (Equation 2.10), and the hydrogeologic parameters shown on Figure E-30, the theoretical, parabola-shaped water table profile between Locations A and B can be calculated. The results are shown on Figure E-31. The upper profile on this figure and the first column in the accompanying table represent the continuous water surface profile from Location A to Location B under the estimated long-term average flow conditions.

TABLE E-8

WETLAND GEOMORPHOLOGIC AND HYDROLOGIC CLASSIFICATION SYSTEM (after Brinson 1986)

Geomorphologic/ Hydrologic Category	Watershed Position	Associated Permanent Surface Water Body	Contributing[1] Watershed Area Scale	Primary[2] Hydrologic Inflows	Hydroperiod[3] Predictability	Examples
Basin	Upland, Headwater Areas	None	1	P	L	Bogs
		None	1	P,Qgw	L-M	Fens
		None	1	P, Qd	L	Prairie Potholes
Riverine	Widespread Adjacent to Streams & Rivers	Perennial Streams & Rivers	2, 3	P, Qd, Qgw	L-M	Bottomland Hardwood Swamps
		Perennial Streams & Rivers	2, 3	P, Qd, Qgw	M	Alluvial Swamps
Fringe	Base of Watershed	Lakes/Reservoirs	2, 3	P, Qd, Qgw	M-H	Inland Freshwater Marshes
		Estuaries	3	P, Qd, Qgw	H	Tidal Freshwater Marshes
		Oceans	4	P, Qd, Qgw	H	Tidal Salt Marshes

Notes: [1]Contributing Watershed Area-Scale:
1 = Upland drainage basins
2 = Small watersheds/low stream order
3 = Large, regional watersheds/high stream order
4 = Continental land mass

[2]Primary Hydrologic Inflows:
P = Precipitation
Qd = Direct Runoff (Surface and Interflow)
Qgw = Groundwater Flow

[3]Hydroperiod Predictability:
L = Low
M = Medium
H = High

E.3.3 THE WETLAND WATER BALANCE

E.3.3.1 Overview

The concept of a hydrologic water balance was introduced in Section E.2.5. As stated there, water balances can be performed for control volumes of any size, ranging from sub-watershed units to global zones. Many wetland researchers have attempted to quantify the water balance of wetlands using a variety of measurement and analytical techniques. In this section, the subject of wetland water balances is addressed briefly and from an entirely utilitarian standpoint. The purpose of the discussion is threefold:

- To identify the components of a wetland water balance;
- To indicate how these components can be measured or estimated, and with what degree of accuracy; and
- To suggest the conditions under which water balance analyses are useful for wetland replacement design—and, conversely, when they are not necessary.

These objectives are relatively focused and do not constitute a detailed assessment of water balance theory, application, or hydrologic measurement techniques. For a more in-depth discussion of this topic, a number of references are available, including: Carter et al. (1978), Heimburg (1984), Kadlek (1983), LaBaugh (1986), Mitsch and Gosselink (1986), Verry and Boelter (1978), and Winter (1981).

E.3.3.2 Wetland Water Balance Equation

As discussed in Section E.2.5, and summarized by Equation 2.11, the underlying principle behind water balance analyses is that, during a given time period, the inflow to a control volume minus the outflow must equal the change in water storage within the volume. Depending upon the type of wetland under consideration and the purpose of the water balance analysis, various inflow and outflow terms may be used to express this relationship. A general form of the wetland water balance equation is:

$$(P + Qdi + Qgwi) - (ET + Qdo + Qgwo) = dS \qquad [3.1]$$

where, P = net precipitation
Qdi = direct runoff (i.e., surface) inflow
Qgwi = groundwater inflow
ET = actual evapotranspiration
Qdo = direct runoff (i.e., surface) outflow
Qgwo = groundwater outflow
dS = change in water storage

In the above equation, the first set of terms in parentheses represents inflows, while the second set represents outflows. All of these terms can be expressed in units of volume (L**3) during a given time interval or, alternately, for a known wetland area, they can be expressed in terms of depth (L, e.g., inches) across the (average) wetland area during that time interval. Table E-9 schematically illustrates the relationship between these water balance terms and also summarizes their annual values, as estimated by various wetland researchers for different wetlands and summarized by Mitsch and Gosselink (1986, page 61).

In some wetland water balances, the inflow/outflow terms in Equation 3.1 are combined. For example, Sourballe (1987) combines "Qdi" and "Qgwi" into a single term representing upland surface and groundwater inputs to the wetland. Other researchers have ignored the "Qgwo" term (a reasonable assumption for wetlands which are gaining year-round). Others have disregarded the "Qdo" term (rea-sonable for wetlands with no surface water outlet). For our purposes, as discussed below, a simplified form of the water balance equation is:

$$(P + Qdi) - (ET + I + SWo) = dS \qquad [3.2]$$

where, I = infiltration from wetland
Swo = surface water outflow through outlet
(All other terms are as previously defined.)

This equation is applicable for basin wetlands which lie above the permanent water table (i.e., Qgwi = 0), whose outflow includes evapotranspiration (ET), infiltration through the wetland bottom (I), and occasional surface water outflow (SWo) during storm events which produce runoff in excess of the wetland's storage capacity. Section E.3.3.4 presents the rationale for reducing the general water balance equation to this simpler form for basin wetlands. It should be noted that for stable wetlands over an extended time period inflows balance outflows and the change in water level within the wetland approaches zero (i.e., dS = 0). However, over shorter periods of time, there may be significant rises or falls in wetland water levels,corresponding with increases or decreases in water storage, respectively. Therefore, for the sake of general applicability, Equations 3.1 and 3.2 both include a potentially non-zero "dS" term on their right-hand sides.

E.3.3.3 Evaluation of Water Balance Terms

This section contains a brief discussion of how the individual components of a wetland water balance (Equation 3.1) can be measured in the field and how they can be estimated for future wetland replacement sites. Although field measurement of hydrologic inflows and outflows is important from a research standpoint and is also necessary in some cases to validate the performance of created and restored wetlands, there are a number of serious limitations associated with the use of field measurements as a practical, predictive tool for wetland replacement design. For one, they are usually very expensive and time-consuming. Accurate and meaningful calibration of a wetland water balance requires the long-term monitoring of precipitation and other climatic factors as well as surface water and groundwater levels and flow conditions. Furthermore, it requires a reasonably accurate evaluation of some physical parameters (e.g., hydraulic conductivity) which are often both extremely variable in nature and very difficult to measure by either field or laboratory methods. Another problem with field calibration studies is that the results are generally not transferrable from one wetland to another. The climatic and hydrogeological conditions which control the water balance of a wetland are unique to each site. Even wetlands that appear to be very similar may have much different water balances, due to such small-scale and difficult-to-measure differences as a thin underlying impermeable zone or differing degrees of peat decomposition. Finally, the water balance results from even a single wetland may not be transferrable from one time to another. For example, a detailed field calibration study of a wetland during a relatively dry season or year might

CALIBRATION OF A WETLAND WATER BALANCE

Accurate and meaningful calibration of a wetland water balance requires the long-term monitoring of precipitation and other climatic factors, as well as surface groundwater levels and flow conditions. Furthermore, it requires a reasonably accurate evaluation of some physical parameters which are often both extremely variable in nature and very difficult to measure by either field or lab methods.

indicate a much different relationship between water balance terms (e.g., the ratio of groundwater to surface water inflow) than would an identical field calibration study of the same wetland conducted during a wet year.

Notwithstanding the above limitations, the following discussion addresses—albeit briefly—the field measurement of a wetland's hydrologic inflows and outflows. Emphasis is given, however, to the prediction, rather than to the actual measurement of these terms, since wetland replacement design essentially requires predictive hydrologic analysis.

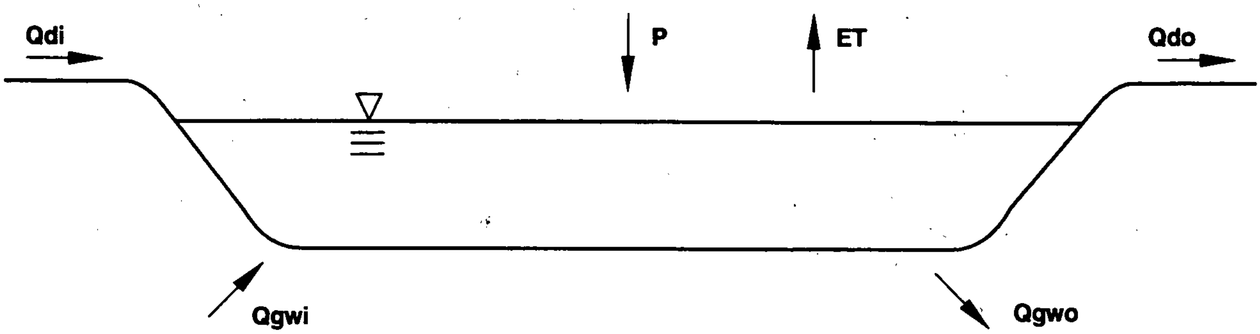
E.3.3.3.1 Precipitation: The measurement of precipitation using standard, National Weather Service (NWS) precipitation gages is well established and relatively accurate in practice. For individual stations, Winter (1981) indicates that instrument errors can be in the range of 1 to 5 percent, whereas errors related to the placement of gages (e.g., height above ground level) can range from 5 to 15 percent for long-term data. Although the areal averaging of point precipitation data, using techniques such as the Thiessen Polygon and Isohyetal methods, can involve much higher relative errors than these over short time periods. The errors decrease as the gage density and averaging time increase. Winter (1981) estimates that such techniques for areal averaging produce overall errors in monthly precipitation estimates of approximately 10 to 20 percent and in seasonal estimates of about 5 percent.

For wetland replacement design, estimates of precipitation at a site are usually made on the basis of existing gage data, either from single precipitation gages located nearby, or using a precipitation gage network and regionalization techniques. Although precipitation records are usually available and easily accessible, they may not be in the form required for wetland hydrologic design. Most existing statistical representations of precipitation data address storm events rather than conditions of low precipitation. For example, publications such as *Technical Paper No. 40—Rainfall Frequency Atlas for the United States* (U.S. Weather Bureau 1961), which are well known and widely used by almost all stormwater drainage designers, have little application in wetland replacement design other than for the sizing of spillways and outlet works. For wetland design, the more important but usually much less available, statistical analyses are those dealing with precipitation during extended dry-weather periods. Examples of the need for such data and possible ways to obtain or develop it are presented below.

Hydrologic water balances are often performed on a monthly basis (e.g., example problem in Section E.3.3.5). Numerous climatological data reports are available from the National Weather Service, including local, regional, and national summaries, which indicate the long-term monthly precipitation values at NWS stations. These monthly average values are sufficient for use in estimating the inflow to a wetland from precipitation falling directly on the wetland surface, but they do not allow quantification of the usually much larger component of direct runoff (Qd) from the tributary watershed. The reason for this is that runoff from precipitation is highly dependent upon the distribution as well as the total amount of precipitation. For example, using the SCS Method for runoff estimation (Section E.2.4.2.2), consider a watershed with a runoff curve number (CN) of 80 and an average monthly precipitation (for any given month) of 4.00 inches. As discussed previously, initial abstraction (Ia) must be satisfied before direct runoff from a precipitation event commences. Equation 2.5 indicates that initial abstraction is a singular function of curve number. For a CN of 80, the "threshold" precipitation, i.e., the minimum 24-hour precipitation producing direct runoff, is 0.50 inches in the above example. (This can also be seen from Figure E-16.) Unless we have further information concerning the distribution of the 4.00-inch average monthly precipitation, direct runoff cannot be determined. The example watershed could produce a direct runoff ranging anywhere from zero (if precipitation were lightly and evenly distributed over the month) to over 2 inches (if the monthly precipitation occurred all in a single, one-day storm). Obviously, more information is needed or assumptions must be made, before a wetland water balance can be completed using monthly precipitation averages. Several approaches are possible:

TABLE E-9

WETLAND WATER BALANCE



Estimated Annual Water Balances by Different Researchers (After Mitsch and Gosselink, 1986, p. 61)							
	Water Balance Terms (inches/year)						
Study Location	P	Qdi	Qgwi	ET	Qdo	Qgwo	dS
Okefenokee Swamp, Georgia	51.5	←15.5→		36.7	28.8	1.5	0
Green Swamp, Florida	35.0 to 71.0	0	0	34.0 to 39.0	2.0 to 31.0	1.8 to 2.2	-4.0
Alluvial Cypress Swamp, So. Illinois	29.1	90.2	8.7	28.4	91.3	8.3	0
Prairie Pothole, North Dakota	14.2	15.7	0	24.8	0	7.1	+0.2
Rich Fen, North Wales	40.2	←15.0→		19.3	39.4	0	-3.5

- Multi-year **daily** precipitation data can be obtained and statistical frequency analyses performed for use in a **daily** (rather than monthly) wetland water balance. Although time-consuming, this is a viable approach. The necessary data are available either directly from NWS Climatological Data reports or from several private data-supply firms which can provide extensive NWS climatological data bases in computerized format. (Refer to Section E.2.6.5 for general sources of hydrologic data.)

- The water balance can be performed using actual daily precipitation data for an extended time period rather than precipitation frequency analyses. This approach is not uncommon in other hydrologic analyses. For example, the popular *Hydrologic Evaluation of Landfill Performance* (HELP) computer model (Schroeder et al. 1984), developed for the U.S. Environmental Protection Agency incorporates five years of daily precipitation values and other climatological data for 102 cities across the United States to calculate the runoff, evapotranspiration, and infiltration through landfill covers. Such an approach does not produce statistical frequencies, but it does indicate how a hydrologic unit will perform on the basis of real historical inputs.

- Available NWS data can be manipulated to generate approximate, runoff-producing distributions of monthly precipitation averages. For example, *Climatography of the United States No. 90* (U.S. National Oceanic and Atmospheric Administration 1978), indicates the average number of days per month, based on long-term records of many NWS precipitation stations across the United States, that daily precipitation exceeds 0.01 inches, 0.1 inches, 0.5 inches, and 1.0 inches. In combination with monthly or annual precipitation averages, and given the threshold runoff-producing precipitation for a given watershed, these data can be used to develop an approximate distribution of total precipitation for use in calculating runoff as part of wetland water balance. The method is illustrated in Example B, and the results are used in the wetland water balance example of Section E.3.3.5.

WATER BALANCE & RUNOFF-PRODUCING PRECIPITATION

National Weather Service data can be manipulated to generate approximate run-off producing distributions of monthly precipitation averages. In combination with monthly or annual precipitation averages, and given the threshold runoff-producing precipitation for a given watershed, these data can be used to develop an approximate distribution of total precipitation for use in calculating runoff as part of wetland water balance.

E.3.3.3.2 Evapotranspiration: As an "invisible" process, evapotranspiration is difficult to measure or to quantify. For this reason, many wetland water balance studies have treated it as a residual term, i.e., calculated evapotranspiration as the difference between other measured or directly calculated components of the water balance equation. The problem with this approach is that "evapotranspiration" actually includes the errors—some potentially large—inherent in the measurement or calculation of all other terms. In those relatively few wetland studies which have attempted to measure evapotranspiration directly, the most common approach has been to use evapotranspirometers or lysimeters. As discussed in Section E.2.3.3, however, these field instruments are generally not very reliable due to their inability to simulate natural conditions accurately. Other researchers have attempted to estimate evapotranspiration by analysis of the difference between daytime and nighttime water level fluctuations in a wetland, with the former (but not the latter) including significant losses due to evapotranspiration.

From the standpoint of wetland replacement design (versus research or calibration studies), the two most useful approaches for estimating wetland evapotranspiration are the use of evaporation pan data and the application of empirical formulas based upon meteorological data. The National Weather Service collects and reports evaporation pan data at numerous stations. After conversion to free-water evaporation by an appropriate pan coefficient (Section E.2.3.3), these data can be used to represent **potential** evapotranspiration (PET) from an open water body or saturated soil surface. Winter (1981) cautions, however, that evaporation pans should be used to calculate evaporation only on the basis of annual data and annual water budgets. Despite this caution, the use of evaporation pan data in monthly wetland water budgets is not uncommon.

Another common approach is the use of empirical equations, such as those of Thornwaite and Mather (1955), Blaney and Criddle (1950), Penman (1948), etc. In general, these equations are very sensitive to the selection of empirical coefficients which are used for their solution. They have not been sufficiently calibrated or validated during wetland studies to justify the recommendation of any one method over the others. In fact, a comparison of the results from several different equations would appear to be prudent for those wetland replacement projects which require a detailed water balance. The water balance example in Section E.3.3.5 uses the Thornwaite and Mather (1955) method for illustrative purposes only and not necessarily as a recommendation of this method over the others indicated above.

E.3.3.3.3 Direct (Surface) Runoff: Direct surface runoff, both into and out of a wetland, can be measured by a variety of standardized and reliable techniques when the flow is channelized or when it occurs as discharge through a fixed hydraulic control structure at the inlet or outlet of the wetland. Measurement devices include weirs, flumes, culverts, and a variety of other hydraulic structures for which a relationship can be established between flow depth and discharge. For watercourses, direct runoff is usually measured with current meters set up at regular intervals across a channel cross-section to calculate the total stream discharge at various flow depths. This so-called "rating curve," which was discussed in Section E.2.4.1, can be used to develop the stream hydrograph and to calculate the total channelized surface runoff into a wetland for any given measurement duration.

DEVELOPMENT OF PRECIPITATION DISTRIBUTION FROM ANNUAL AND MONTHLY AVERAGES

EXAMPLE B:

Location:	Columbus, Ohio
Watershed CN =	81 (see Water Balance Example, Section E.3.3.5)
Minimum Runoff-Producing Precipitation =	IA = (200/CN-2) = 0.47 in. [Eq. 2.5]
Average Annual Precipitation =	37.01 in. (U.S. NOAA, 1980)

Average Annual Days with Precipitation Exceeding[1]		Precipitation Range	Average Precipitation[2]	No. Days with Precipitation within range	Watershed QD per Day[3]	Total Watershed QD
Depth	No. Days					
0.01	137	0.01 - 0.1	0.04	55	0	0
0.1	82	0.1 - 0.5	0.23	57	0	0
0.5	25	0.5 - 1.0	0.67	17	0.02	0.34
1.0	8	1.0+	1.29[4]	8	0.21	1.68

Total Annual Qd = 2.02

Notes: All values in inches unless otherwise noted

[1] From *Climatography of the United States No. 90* (U.S. NOAA 1978)
[2] Assumed one-third range values
[3] Calculated by SCS Method for Avg. Precip. values [Eq. 2.2 & 2.3]
[4] Calculated as "X" value where:

$$(0.04 \text{ in})\,(55 \text{ days}) + (0.23)\,(57) + (0.67)\,(17) + (x)\,(8) = 37.01$$

$$x = 1.29 \text{ inches}$$

Winter (1981) has estimated that the error associated with surface runoff measurements using the above techniques can typically be kept to around 5 to 10 percent.

The measurement of non-channelized surface runoff (i.e., overland flow) and shallow subsurface flow (interflow) to a wetland is problematic. In fact, there are no practical methods for the measurement of either of these components of direct runoff. Fortunately, true overland flow is relatively rare, since surface water tends to channelize within very short distances of its origin. Likewise, interflow is usually significant only over an area in nearby proximity to a wetland. It, too, tends to channelize quickly. For wetlands with relatively large tributary watersheds, the errors in direct surface runoff calibration associated with failure to measure overland flow and interflow are probably minor, provided that all channelized and/or structurally-controlled flows into and out of the wetland are monitored.

For wetland replacement design, our primary concern is with the estimation of direct runoff to a wetland produced by varying amounts and distributions of precipitation. Alternate methods for predicting direct runoff were presented in Section E.2.4.2. Among these, the method which is most convenient, and which has been most widely applied for wetland design, is the Soil Conservation Service (SCS) soil-cover-complex method. This can be used to estimate both the total volume of direct runoff (Qd) and the direct runoff hydrograph. Its use is illustrated in the following example of a water balance problem.

E.3.3.3.4 Groundwater Flow: Like evapotranspiration, the process of groundwater flow cannot be seen and is very difficult to directly measure. This limitation is even more important in the case of groundwater, however, since its absolute value can be much higher than that of evapotranspiration, and its variation is often much greater. Unlike evapotranspiration, which is always an outflow component in a wetland's water balance, groundwater can flow either into or out of a wetland. In fact, it is not uncommon for groundwater flow to reverse directions during the course of a year in response to rising and falling water table levels which can produce alternate gaining and losing conditions within a wetland. Moreover, a single wetland may simultaneously experience gaining conditions in one area and losing conditions in another (Hollands 1987).

Measurement of groundwater flow was discussed previously in Section E.2.4.3.3. The only instrument for directly measuring groundwater flow into a wetland is the seepage meter. Although such measurement eliminates the need to estimate the distribution of head and hydraulic conductivity within an aquifer, it does not reveal the hydrogeologic conditions producing groundwater flow, and it does not provide a basis for estimating how groundwater flow would respond to changing hydrogeologic conditions. Moreover, the effective use of seepage meters is usually limited to relatively permeable mineral soils. On the other hand, the estimation of groundwater flow by flow net analysis is extremely difficult and prone to a high degree of error (at least one order of magnitude). This is especially true for wetland studies due to the following factors:

- Many wetlands are at least partially underlain by organic soils (histosols). The hydrology of these histosols, particularly their hydraulic conductivity, is poorly understood and subject to very large variations. Verry and Boelter (1978) discuss three classes of organic peats: fibric, hemic, and sapric. Fibric peats have relatively little decomposition of organic material, high fiber contents (more than 67 percent), and high values of hydraulic conductivity (K); hemic peats have intermediate decomposition, fiber content and "K"; sapric peats are the most decomposed, and have the lowest fiber contents (less than 33 percent) and "K" values. The hydraulic conductivities of fibric peats can be over three orders of magnitude (i.e., a thousand times) greater than those of sapric peats (Verry and Boelter 1978).

- Fine-grained mineral and organic soils are also complex in terms of their hydraulic gradients and flow properties. Some researchers have suggested that Darcy's Law (Equation 2.7) may not apply for very low-permeability soils or that there may be a threshold hydraulic gradient below which flow does not occur (Freeze and Cherry 1979).

  In any case, the extremely slow flow through some fine-grained and organic soils makes the measurement of their hydrogeologic properties very difficult.

- The distribution of peats and mineral soils within a wetland is often quite variable in terms of depth and area. Hydraulic conductivity tends to decrease rapidly with depth in histosols (Bardecki 1987). Also, wetlands tend to have finer-textured sediments near their centers and coarser-textured substrates toward their shores (Zimmerman 1987). Moreover, this variable distribution of wetland sediments is changeable over time.

In light of the above discussion, it is not surprising that groundwater flow is usually calculated as a residual term in wetland water balances and seldom measured directly. Even with provisions for extensive and long-term groundwater monitoring, it is doubtful that the error in this term could be consistently reduced to less than an order of magnitude. For wetland replacement design, the prediction of groundwater flow into and out of a proposed wetland site is even more difficult since there is often virtually no measurement or forecasting data available. Fortunately, as discussed in Section E.3.3.4, there is seldom a need for quantification of this term except in the case of basin wetlands located above the water table for which the groundwater flow terms in the water balance equation can be replaced by infiltration outflow (Equation 3.2). The following discussion concerns the quantification of this infiltration (I) component of the water balance.

Although infiltration from a wetland is somewhat less complex than the more general condition of groundwater inflow/outflow, the subject is by no means a simple one. In fact, infiltration itself is a very complex physical process, whose evaluation requires not only a knowledge of fluid flow through saturated soils but also an understanding of unsaturated flow phenomena. While this subject is beyond the present scope, a few words concerning it are in order. Figure E-14 illustrates a typical infiltration capacity curve. As seen from this curve, infiltration into an initially dry soil decreases with time and eventually approaches a steady-state value. During this time period, an infiltration moisture profile is developed within the soil. This profile extends from the ground surface, which becomes fully saturated after a relatively short period of time, downward to a wetting front, where the soil moisture content is at its initial (relatively dry) condition. As this profile develops, soil moisture conditions change as do the physical parameters controlling flow through the soil.

Darcy's Law (Equation 2.7) has been applied to infiltration analyses with rearrangement of terms to the following form:

$$I = Q/A = -Ki \qquad [3.3]$$

where, I = infiltration rate [L/T]
K = hydraulic conductivity [L/T]
I = hydraulic gradient [L/L]

The apparent simplicity of this equation is deceiving. For unsaturated flow, hydraulic conductivity (K) is not only a complex function of soil properties but also of the soil's water content. Its value increases with increasing water content, reaching a "saturated" level at a water content of 100 percent. (Previously, the term "hydraulic conductivity" has been used to refer to this saturated "K" value.) Prior to saturation, the hydraulic gradient in Equation 3.3 is also more complicated than for saturated flow since hydraulic head includes both gravitational and suction components, the latter being related to capillary forces within the soil.

For a wetland with permanent standing water, the above conditions are somewhat simplified. Assuming the soil to be fully saturated in this case, the suction gradient is negligible, the gravitational hydraulic gradient (i) has a value of unity, and infiltration (I) approaches a limiting value of saturated hydraulic conductivity (Hillel 1971). This saturated "K" value is still a very complex term which depends upon a variety of soil properties (e.g., texture, structure) and which tends in nature to occur in heterogeneous and anisotropic distributions. However, for simplicity and practicality, a number of researchers have developed approximate correlations between "K" and a variety of easily measured or calculated soil properties. For example, Rawls et al. (1982) have performed a comprehensive literature search to establish a relationship between saturated hydraulic conductivity and the major U.S. Soil Conservation Service (SCS) soil texture classes. Their results are presented in Table E-10 together with an illustration of the relationship between saturated and unsaturated "K" values for these texture classes. Figure E-32 indicates how these SCS soil texture classes are defined. Although empirical relationships such as this one greatly oversimplify the actual effect of soil properties upon hydraulic conductivity and represent only rough approximations to its actual value, they are nonetheless convenient and—in one form or another—necessary for the performance of water balances at some potential future wetland sites. Table E-10 is used in the following water balance example to estimate infiltration (I) from a basin wetland.

Infiltration at a wetland replacement site can also be estimated by performing direct measurements of site soils either in the laboratory or in the field. As indicated by the above discussion, infiltration rate (I) approaches hydraulic conductivity (K) in the case of a standing water body above a fully saturated soil. Laboratory and field methods for the measurement of "K" were previously discussed in Section E.2.4.3.3. In addition, there are a number of different types of infiltrometers which can be used to measure infiltration directly, such as: (i) rainfall simulators, in which water is applied to a small field plot in the form and at a rate comparable to natural rainfall; and (ii) flooding-type infiltrometers (e.g., double-ring infiltrometers), in which water is applied in a thin sheet upon an enclosed area under a constant or variable head (Musgrave and Holtan 1964). Other methods for estimating infiltration rate in the field include percolation tests, which are routinely used for the design of septic systems and which can be performed quickly and inexpensively (U.S. Department of Health, Education, and Welfare 1957), and tube infiltration tests, which are often used to estimate infiltration into irrigated soils (Linsley and Franzini 1972).

There are several important practical problems associated with the above methods for direct measurement of infiltration. One is that they tend to produce widely differing results, sometimes by an order of magnitude and more. Also, they cannot predict the spatial and vertical distribution of infiltration capacity which tend to develop in most wetlands over time or the changes in time which frequently occur as organic soils accumulate and reach varying stages of decomposition in the wetland substrate. As a result of these measurement difficulties, the rate of infiltration from a basin wetland—while recognized to be a very important, sometimes dominant water balance term—is extremely difficult to estimate accurately in advance at a proposed wetland replacement site.

E.3.3.3.5 Change in Storage: The change in storage (dS) within a wetland during a given time period is equal to the average wetland area multiplied by the change in water level during that time period. Water level is typically measured by observation of staff gages or through the use of permanent water level recorders. Area is a function of water depth. For a given or proposed wetland topography and design configuration, surface area can be calculated for different depths and developed into a stage-area or stage-volume curve, as demonstrated in the following water balance example.

TABLE E-10

SATURATED HYDRAULIC CONDUCTIVITY VERSUS SCS SOIL TEXTURE CLASS

SCS Soil Texture Class	Saturated Hydraulic Conductivity (K)		
	cm/hr	cm/sec	in/day
Sand	21.00	5.8×10^{-2}	200
Loamy sand	6.11	1.7×10^{-3}	58
Sandy loam	2.59	7.2×10^{-4}	24
Loam	1.32	3.7×10^{-4}	12
Silt loam	0.68	1.9×10^{-4}	6.4
Sandy clay/loam	0.43	1.2×10^{-4}	4.1
Clay loam	0.23	6.4×10^{-5}	2.2
Silty clay loam	0.15	4.2×10^{-5}	1.4
Sandy clay	0.12	3.3×10^{-5}	1.1
Silty clay	0.09	2.5×10^{-5}	0.85
Clay	0.06	1.7×10^{-5}	0.57

E.3.3.4 Determining the Need for a Water Balance

The discussion of wetland water balances to this point has focused upon their general form and the evaluation of component inflows and outflows. A more fundamental question, however, is, "Why perform a water balance at all?" Considering the difficulty entailed in such analyses, the general lack of precision and accuracy which they almost always involve, and the cost and time required for hydrologic field measurements, the question is not a trivial one.

From a research or field verification standpoint, water balance studies are required for a true understanding of all wetlands. The magnitude of and relationship between individual hydrologic inflow and outflow terms have a direct bearing upon a wetland's structure and function. Nutrient and chemical input-output balances from a wetland are based upon and controlled by the hydrologic water balance. For such nutrient and chemical balances, knowledge of the net inflow and outflow, even if entirely accurate, is not sufficient. The relationship between the component terms which make up these inflows and outflows must also be known. For example, a wetland receiving a fixed input of combined surface runoff and groundwater flow may have a much different structure if the groundwater/surface water ratio is high (tending to produce mineral-rich conditions) than if it is low.

Notwithstanding the above discussion, successful wetland replacement design, unlike wetland research, does not always require an in-depth understanding of a wetland's water balance. As discussed in Section E.3.1, a reasonably accurate assessment of hydroperiod during the growing season is sufficient for the design of most replacement wetlands. Since hydroperiod essentially represents an integration of all wetland inflows and outflows, its assessment as a "lumped" parameter—where possible—does not necessarily require the quantification of all the individual terms comprising it. The question is, however, under what conditions can hydroperiod be evaluated using such an holistic approach? Referring to the wetland classification system in Table E-8, it can be seen that the hydroperiods of riverine and fringe wetlands are controlled largely by the water levels in their adjacent, permanent surface water bodies, assuming that direct hydraulic contact is created or maintained between these wetlands and adjacent surface waters. As a practical matter, the watershed area directly tributary to a riverine or fringe wetland is very seldom large enough to affect significantly the water levels within the adjacent river, lake, estuary, etc. The water balance (or flow-through) components of the wetland are, likewise, typically insignificant in comparison with the magnitude of potential flow provided by the permanent water supply source. For the sole purpose of wetland replacement design, detailed water balance studies are usually unnecessary for riverine or fringe wetlands.

HYDROPERIOD ASSESSMENT AND WETLAND REPLACEMENT DESIGN

Successful wetland replacement design, unlike wetland research, does not always require an in-depth understanding of a wetland's water balance. A reasonably accurate assessment of hydroperiod during the growing season is sufficient for the design of most replacement wetlands.

The situation is not as simple or convenient for basin wetlands, however. These are supported by much smaller watersheds and do not have adjacent surface water bodies which independently control their hydroperiods. This is especially true in the case of basin wetlands which occur above the permanent water table and, therefore, do not experience the relative stabilizing influence of groundwater inflow for support. Such basin wetlands, located in upland headwater areas, essentially create and control their own hydroperiods. For them, water balance analyses are required for wetland replacement design. An example is provided in the following section.

For the sole purpose of wetland replacement design, detailed water balance studies are usually unnecessary for riverine or fringe wetlands.

E.3.3.5 Example Water Balance for a Basin Wetland

The example in this section has been prepared to illustrate one method for performing a water balance analysis of a basin wetland. As the following description suggests, the procedure uses a number of assumptions and arbitrarily selected hydrologic methods for calculating inflows and outflows. The use of these assumptions and methods is intended for illustrative purposes only and is not meant as a general endorsement of their applicability. Hydrologic design of replacement wetlands requires a considerable amount of professional judgement and cannot be reduced to a "cookbook" format or procedure or to a uniformly applicable set of hydrologic assumptions and methods.

As indicated by Figure E-33, the example involves two potential wetland replacement sites, one in Columbus, Ohio, and one in Bismarck, North Dakota. The watershed and proposed wetland configuration data for these two projects are identical. In fact, the two water balances are identical in all respects except for location-related climatological data. As indicated by Figure E-33, the SCS method is used to calculate direct runoff (Qd) for this example. The weighted curve number has been calculated using the procedures and parameter values provided in Section E.2.4.2.2. Figure E-33 also illustrates the construction of a wetland stage-area curve, using the assumed geometric size and shape factors indicated. Other information provided on this figure is discussed below.

HYDROLOGY IN BASIN WETLANDS

Basin wetlands which occur above the permanent water table do not experience the relative stabilizing influence of groundwater inflow for support. Basin wetlands located in upland, headwater areas essentially create and control their own hydroperiods. For them, water balance analyses are required for wetland replacement design.

Tables E-11a and E-11b indicate the iterative water balance solution procedure for the Columbus and Bismarck sites, respectively. The basic approach is similar to hydrologic flood routing through reservoirs. By this approach, a wetland storage depth (S2) at the end of each routing period (month) is assumed and used as the basis for inflow/outflow calculations during that period. These calculations produce a calculated "S2" value, which is compared with the initially assumed value. If they are not equal or reasonably close, the initial assumption is revised and inflow/outflow calculations are modified successively, until closure between the assumed and calculated "S2" values is achieved. The governing equation for these calculations is Equation 3.2, which applies to basin wetlands located above (i.e., do not intersect) the water table. This water balance example has been performed for monthly time increments, although the procedure could be applied in the same manner for different selected periods such as during the growing season.

The following description indicates how the values on Tables E-11a and E-11b are calculated, row by row:

Rows 1 through 5: Initial Values

Row 1 Indicates the starting storage depth (S1) in each month. For the initial month (January), the wetland has been assumed to be empty at the outset (i.e., S1=0). The calculated results bear out the reasonableness of this assumption. For succeeding months, (S1) is equal to the calculated end-of-month storage depth (S2) for the preceding month. It should be noted that (S1) and all other terms on Tables E-12a and E-12b are expressed in units of "wetland inches." These units must be distinguished from "watershed inches" of runoff, as discussed below.

Row 2 Indicates the initial assumption for end-of-month storage depth (S2). The asterisk (*) notation on this and some succeeding rows indicates that this is an iterative line, which is adjusted on the basis of trial-and-error calculations.

Row 3 Indicates the monthly average storage depth within the wetland (Savg), which is simply assumed equal to the average of beginning (S1) and ending (S2) storage depths.

Row 3 = (Row 1 + Row 2)/2

Row 4 Is the monthly average watershed surface area (Aavg), in acres, corresponding with (Savg) in the previous row. (Aavg) is determined by referring to the stage-area curve in Figure E-33, with stage being equal to (Savg).

Row 5 Is the average available storage depth during the month, calculated as the difference between the maximum, or overflow, storage depth shown on Figure E-33 (Smax = 48 in.) and the average monthly storage depth within the wetland (Savg). This available storage depth is needed to determine, during runoff-producing precipitation days, how much surface water outflow (SWo) escapes from the wetland.

Row 5 = 48 in. - Row 3

Rows 6 through 14: Inflow Values

Row 6 Is the average monthly precipitation (P) for the wetland location site. In this example, (P) is taken directly from NWS climatological data reports for the Columbus, Ohio, and Bismarck, North Dakota, precipitation stations.

Row 7 Indicates the average number of days per month with 24-hour precipitation in the range of 0.5 to 1.0 inches. This information is obtained from NOAA's *Climatography of the United States No. 90* (1978), as shown and discussed previously in Example B.

Row 8 Is the average watershed runoff per day, in **watershed** inches, when daily precipitation is in the range of 0.5 to 1.0 inches. Example B indicates how this value is calculated, based upon a hypothetical precipitation distribution obtained from annual and monthly precipitation totals.

Row 9 Is the average watershed runoff per day, in **wetland** inches, corresponding to Row 8. The conversion from watershed to wetland inches requires multiplication by the ratio of watershed to wetland area. Since average wetland area per month (Aavg, Row 4) is a function of storage depth, this row is iterative.

Row 9 = (Row 8) x (200 acres/Row 4)

Row 10 Is the average number of days per month with 24-hour precipitation greater than 1.0 inch. The value is determined from Example B.

Row 11 Is the average watershed runoff per day, in **watershed** inches, when daily precipitation exceeds 1.0 inches. Again, the value is taken from Example B.

Row 12 Is the average watershed runoff per day, in **wetland** inches, corresponding to Row 11. As in Row 9, the conversion from watershed to wetland inches requires multiplication by the respective area ratio.

Row 12 = (Row 11) x (200 acres/Row 4)

Row 13 Indicates the total watershed runoff (Qd) for the month, in **watershed** inches. It is calculated by multiplying the number of days with precipitation between 0.5 and 1.0 inches times the average watershed runoff on those days and adding to this the product of greater-than-one-inch precipitation days times the average watershed runoff on those days.

Row 13 = (Row 7 x Row 8) + (Row 10 x Row 11)

Row 14 Indicates the corresponding watershed runoff (Qd) for the month, in wetland inches. It is calculated using the same area ratio as above.

Row 14 = (Row 13) x (200 acres/Row 4)

Rows 15 through 22: Outflow Values

Row 15 Indicates the average daily temperature for the month, in degrees Fahrenheit, as determined from NWS climatological data reports for Columbus and Bismarck.

Row 16 Is the monthly heat index (dimensionless) corresponding to the average monthly temperature in Row 15. Heat index values are determined from Table 1 of Thornwaite and Mather (1957). The Thornwaite and Mather method is one of a number of empirical procedures for determining potential evapotranspiration (PET). It can be used to estimate PET on a daily or monthly basis.

Row 17 Is the unadjusted daily value for PET, determined from Table 3 in Thornwaite and Mather (1957), using the average monthly temperature and the total annual heat index value. Total annual heat index is calculated as the sum of monthly values.

Row 18 Is an adjustment factor for converting unadjusted daily PET to adjusted monthly PET. Its value is determined from Table 6 of Thornwaite and Mather (1957), based upon the latitude of the study site (40 degrees north for Columbus; 47 degrees north for Bismarck). This factor reflects the number of days per month and the number of sunlight hours per day at each location, during which evapotranspiration occurs.

Row 19 Is the adjusted monthly potential evapotranspiration (PET), which is calculated simply by multiplying the unadjusted daily value (Row 17) by the monthly adjustment factor (Row 18). Potential evapotranspiration is a reasonable approximation of actual evapotranspiration (AET) whenever the wetland contains standing water or its soil is fully saturated. Otherwise, AET is less than PET. For this analysis, PET is used year-round as a surrogate for AET.

Row 19 = (Row 17) x (Row 18)

Row 20 Indicates the average infiltration rate in inches per day. Its value is obtained from Table E-10, based upon a projected wetland bottom soil texture of "silty clay loam" (Figure E-33).

Row 21 Indicates the total monthly infiltration (I), taken as the product of infiltration rate times the number of days per month.

Row 21 = (Row 20) x (# days per month)

Row 22 Indicates the total monthly surface water runoff (SWo) from the wetland, expressed in wetland inches. In order to estimate this value, each of the single-day storm events producing runoff is considered independently. The total runoff produced by these storms (Rows 9 and 12) is compared with the average available wetland storage depth for the month (Row 5). Where the runoff from any individual storm exceeds this average available depth, the difference is assumed to pass through the wetland's outlet works and become a part of the total monthly surface water runoff (SWo) value. Total (SWo) is calculated as the sum of the runoff from these individual events.

Row 22 = [Row 7 x (Row 9 - Row 5)]
+ [Row 10 x (Row 12 - Row 5)]
(negative terms treated as zero)

Rows 23 through 24: Water Balance Calculations

Row 23 Is the calculated change in wetland storage during the month, expressed in units of wetland inches. This value is calculated directly from Equation 3.2, the basic water balance equation for basin wetlands without groundwater inflow.

Row 23 = (Row 6 + Row 14) - (Row 19 + Row 21 + Row 22)

Row 24 Is the calculated value of storage depth at the end of the month (S2). It is equal to the initial storage depth (S1, Row 1) plus the monthly change in storage (dS, Row 23). Where (dS) is negative and exceeds (S1), the calculated value of (S2) is set equal to zero. This means that the basin has gone dry during the month, and water level cannot be drawn down farther. As stated above, the calculated value of (S2) is compared with the initially assumed value (Row 2). If they do not match reasonably closely, a new value of (S2) is assumed and the procedure is carried through another iteration.

Row 24 = Row 1 + Row 23 (cannot be less than zero)

The results of the water balance analyses for Columbus, Ohio, and Bismarck, North Dakota, are shown on Table E-11a and E-11b, respectively, and summarized graphically on Figure E-34 in terms of calculated hydroperiod. The primary purpose of this example is to illustrate a possible method for water balance analysis, using hypothetical sites and conditions. Although the numerical results are of secondary importance, they do bear some discussion. Several of the more important findings and related interpretations from these two water balance analyses are as follows:

- In this example, infiltration (I) is the dominant yet most poorly quantified of the water balance terms. The values presented on Table E-10 are rough estimates only and may be accurate to within an order of magnitude. Such potentially large variations in infiltration rate (or saturated hydraulic conductivity) could produce conditions at the Columbus site ranging anywhere from permanently dry to permanently full. In a situation such as this, it would appear prudent during the design phase to place emphasis upon the best possible estimation of infiltration and even to consider methods for controlling it by the selection and preparation of soils during construction to reduce infiltration.

- The disadvantages of monthly (versus shorter term, e.g., daily) water balance analyses are most apparent in the evaluation of runoff inflow (Qd) and surface water outflow (SWo). The former term is based upon the hypothetical precipitation distribution pattern generated from available climatological data totals (Example B). And the latter assumes that runoff produced during these precipitation events will always enter a wetland which is filled to its average monthly storage depth. While both assumptions are reasonable and possibly the best available they are also quite rough. A daily water balance would eliminate most of the uncertainty associated with such assumptions, although the benefit of refining the analysis in such a way is questionable if the above-mentioned uncertainty regarding infiltration could not also be reduced.

- For identical assumptions regarding watershed and wetland parameters, the calculated hydroperiods at Columbus and Bismarck are markedly different, as illustrated by Figure E-34. This difference is due solely to climatic factors, particularly precipitation, and indicates how highly sensitive basin wetlands are to weather conditions. In Bismarck, all other conditions being equal, climate is much less conducive to wetland formation than in Columbus. However, the extensive prairie potholes occurring throughout this region suggest that all other conditions are not equal, and that hydrogeology has a similarly important effect upon the formation and sustenance of wetlands, although more more difficult to quantify. Considering the Columbus site only, it can also be seen by referring to Figures E-6 and E-7 that much different hydroperiods are possible for the same site, based solely upon annual variations in precipitation.

- Although the calculations required for water balances such as the ones in this example can be rather tedious when performed by hand, they lend themselves very readily to numerical solution by computer program or to direct spreadsheet applications.

E.3.3.6 Water Supply Dependability for Basin Wetlands

In the previous section, example water balance analyses were performed for two potential basin wetland restoration sites (Columbus, Ohio, and Bismarck, North Dakota). As indicated and discussed there, the hydroperiods of basin wetlands—particularly those which are not supported by a permanent groundwater table—are highly sensitive to precipitation and resulting stormwater runoff events. In most cases, such wetlands can be expected to go dry seasonally and/or during extended low-precipitation periods. It is important to recognize that such "dry-out" does not represent wetland "failure" but, rather, it is an expected consequence of natural precipitation variability. In most cases, natural, as well as restored, basin wetlands can be expected to go dry under such conditions.

Although vegetation in natural wetlands can often withstand and recover from drought conditions, the vegetation in restored wetlands is generally more sensitive—particularly during the initial period before it has become firmly established. For this reason, although harmful droughts cannot be definitively predicted or always avoided, it would be useful for a wetland restoration designer to know the expected probability of their occurrence. The previous water balance examples (Section E.3.3.5) were based upon long-term average precipitation statistics (e.g., the average number of days during the month of June when precipitation at Columbus, Ohio, exceeds 1.0 inches [Table E-11a]). Although such analyses are useful for evaluating the expected long-term average fluctuation of hydroperiod within a basin wetland, they do not reveal the general statistical probability of his behavior or the specific probability of wetland dry-out for different durations and different seasons. As previously stated, the hydroperiod of basin wetlands is driven directly by precipitation falling over the tributary watershed. Therefore, in order to evaluate the performance of basin wetlands from a probabilistic standpoint, it is necessary first to have sufficient information and data concerning local rainfall event statistics.

The National Climatic Data Center processes daily precipitation data from approximately 20,000 stations nationwide. These long-term precipitation records form an extensive data base which can be used to evaluate statistically the probability of rainfall magnitudes and durations during selected time periods (e.g., hourly, daily, weekly, monthly, seasonally, or annually). Such statistical analyses of precipitation data for storm events are routine and widely used. For example, the *Rainfall Frequency Atlas for the United States* (U.S. Weather Bureau 1961) provides national maps indicating rainfall magnitudes corresponding to various durations (30 minutes to 24 hours) and frequencies (1-year to 100-year return periods). Unfortunately, such statistical analyses or precipitation are typically storm related and generally unavailable for the drought conditions

SOURCE OF LONG-TERM PRECIPITATION RECORDS

The National Climatic Data Center processes daily precipitation data from some 20,000 stations nationwide. These long-term records provide an extensive data basis for statistically evaluating the probability of rainfall magnitudes and durations—hourly, daily, weekly, monthly, seasonally, or annually.

which are more critical to wetland restoration projects. Among the reasons for this are the relatively high level of importance which historically has been placed on the design of storm-related facilities (e.g., flood control and drainage conveyance structures) and the fact that droughts are inherently more difficult to define and analyze than storms (Section E.2.6.1).

In order to identify the problems associated with statistical wetland hydrologic design and to formulate possible approaches to their solution, it is worthwhile to consider again the water balance example for the basin wetland in Columbus, Ohio (Table E-11a, Figures E-33 and E-34). The governing equation for this basin wetland, without groundwater inflow, was previously given in Equation 3.2 as:

$$(P+Qdi) - (ET+I+SWo) = dS$$

Let us assume for purposes of this analysis that we are interested in evaluating the hydroperiod of this wetland under critical conditions, represented by a significant period of low precipitation occurring during the growing season. Assume, further, that the wetland is full at some initial time zero when a period of little or no rainfall commences. If throughout this drought period the cumulative total of precipitation (P) plus direct runoff inflow (Qdi) is less than the cumulative total of actual evapotranspiration (ET) and infiltration outflow (I), the following conditions will apply:

- The wetland will be in a continuous "deficit" condition;
- Storm-related surface water outflow (SWo) will be insignificant; and
- The change in water storage within the wetland (dS) will always be less than or equal to zero. (It will equal zero when the wetland has dried out, i.e., when the water surface elevation [WSEL] within the wetland is less than the basin bottomland elevation.)

Under these conditions, Equation 3.2 reduces to:

$$(P+Qdi) - (ET+I) = dS \qquad [3.4]$$

Now, consider the situation where during the analysis period there is no significant rainfall or runoff from the watershed into the wetland. As indicated by Equation 3.4, the change in storage (negative, indicating a declining water level) is equal to the sum of evapotranspiration (ET) and infiltration (I). As long as there is standing water within the wetland, these two loss terms are relatively constant over short periods. For example, as indicated by Table E-11a, adjusted potential evapotranspiration which is assumed equal to actual evapotranspiration over a standing water body varies from approximately 0.067 to 0.18 inches per day (2.0 to 5.7 inches per month) during the period from April through October. Infiltration, which in this example constitutes a much larger source of water loss than evapotranspiration, is roughly estimated to be 1.4 inches per day on the basis of soil texture (Table E-10). Therefore, the total rate of water loss from this wetland during the growing season without replenishment is estimated to be approximately 1.5 to 1.6 inches per day. This means that from a starting pool depth of 48 inches, the time required for the wetland to go dry is approximately 30 to 32 days. (Note again, as discussed in the previous section, that this calculation and the water balance in general are extremely sensitive to the value of infiltration (I)—a term which is very difficult to estimate precisely.)

The above-calculated dry-out time of approximately one month for this basin wetland can be compared with the expected length of dry periods in the Columbus, Ohio, area. The National Climatic Data Center has developed a number of "Rainfall Event Statistics" based on long-term (minimum 10-year) hourly rainfall data at 3,225 NCDC stations across the United States (Steurer and Nold 1986). One of these statistics is the monthly mean duration of the longest dry period between precipitation events, with precipitation events defined as daily storms having a minimum total accumulation of 0.1 inches and a minimum rate of 0.01

inches per hour. At Columbus, the mean longest dry period between events ranges from 9.1 days in April to 11.9 days in October. From the difference between the required dry-out time and the normal dry period between precipitation events, it is obvious that a basin wetland in Columbus would seldom have time to dry out completely between precipitation events. However, such a comparison does not provide a statistical solution of the actual hydroperiod variation during low-precipitation periods, and it does not answer the question of whether rainfall during such periods is able to maintain or to replenish the wetland water surface elevation.

TABLE E- 11a Water Balance Example – Solution Method (Columbus, Ohio)

Row	Term	January			February			March			April			May			June		
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	S1	0			0			0			0			6			11		
2*	S2-Assumed	0			0			0			12	5	8	18	10		25	31	28
3*	Savg.	0			0			0			6	2.5	4	12	8		18	21	19.5
4*	Aavg.(acres)	1			1			1			1.1	1.05	1.1	1.2	1.15		1.3	1.35	1.35
5*	Avg. Available S	48			48			48			42	45.5	44	36	40		30	27	28.5
	INFLOWS																		
6	P	2.87			2.32			33.4			3.71			4.1			4.13		
7	No. Days with P=0.5"-1.0"	1			1			1			2			3			1		
8	Avg. Watershed Qd/P(0.5-1.0)day	0.02			0.02			0.02			0.02			0.02			0.02		
9*	Avg. Wetland Qd/P(0.5-1.0)day	4			4			4			3.6	3.8	3.6	3.3	3.5		3.1	3	3
10	No. Days with P>1.0"	0			0			0			1			1			2		
11	Avg. Watershed Qd/P(1.0+)day	0.21			0.21			0.21			0.21			0.21			0.21		
12*	Avg. Wetland Qd/P(1.0+)day	42			42			42			38	40	38	35	37		32	31	31
13	Total Watershed Qd	0.02			0.02			0.02			0.25			0.27			0.44		
14*	Total Wetland Qd	4			4			4			45	48	45	45	47		68	65	65
	OUTFLOWS																		
15	T(degrees F)	27			30			40			51			61			70		
16	Monthly Heat Index (Dimensionless)	0			0			0.83			3.11			5.88			8.85		
17	Unadjusted Daily PET	0			0			0.02			0.06			0.09			0.13		
18	Adjustment Factor (Dimensionless)	25.2			24.9			30.9			33.3			37.2			37.5		
19	Adjusted Monthly PET	0			0			0.6			2			3.3			4.9		
20	Infiltration Rate (in/day)	1.4			1.4			1.4			1.4			1.4			1.4		
21	I-Monthly	43			40			43			42			43			42		
22*	Total Wetland SWo	0			0			0			0	0	0	0	0		4	8	5
	WATER BALANCE																		
23*	dS	-36			-34			-36			5	8	5	3	5		21	14	17
24*	S2	0			0			0			5	8	5	9	11		32	25	28

Notes: (1) Unless otherwise indicated, all units are in wetland (versus watershed) inches.

(2) Rows denoted with an * represent iterative (trial-and-error) parameters.

TABLE E-11a (CON'T)

Row	Term	July T1	July T2	July T3	August T1	August T2	August T3	September T1	September T2	September T3	October T1	October T2	October T3	November T1	November T2	November T3	December T1	December T2	December T3	ANNUAL
1	S1	28			14			11			10			0			3			
2*	S2-Assumed	34	8	14	10	11		7	11		0			6	3		0			
3*	Savg.	31	18	21	12	12.5		9	11		5			3	1.5		1.5			
4*	Aavg.(acres)	1.55	1.3	1.35	1.2	1.2		1.15	1.2		1.1			1.05	1.05		1.05			
5*	Avg. Available S	17	30	27	36	35.5		39	37		43			45	46.5		46.5			
	INFLOWS																			
6	P	4.21			2.86			2.41			1.89			2.68			2.39			37.01
7	No. Days with P=0.5"-1.0"	1			2			2			1			1			1			17
8	Avg. Watershed Qd/P(0.5-1.0)day	0.02			0.02			0.02			0.02			0.02			0.02			
9*	Avg. Wetland Qd/P(0.5-1.0)day	2.6	3.1	3	3.3	3.3		3.5	3.3		3.6			3.8	3.8		3.8			
10	No. Days with P>1.0"	1			1			1			0			1			0			8
11	Avg. Watershed Qd/P(1.0+)day	0.21			0.21			0.21			0.21			0.21			0.21			
12*	Avg. Wetland Qd/P(1.0+)day	27	32	31	35	35		37	35		38			40	40		40			
13	Total Watershed Qd	0.23			0.25			0.25			0.02			0.23			0.02			2.02
14*	Total Wetland Qd	30	35	34	42	42		43	42		3.6			43	43		3.8			
	OUTFLOWS																			
15	T(degrees F)	74			72			66			54			42			32			
16	Monthly Heat Index (Dimensionless)	10.3			9.57			7.48			3.87			1.17			0			51.06
17	Unadjusted Daily PET	0.15			0.14			0.12			0.07			0.02			0			
18	Adjustment Factor (Dimensionless)	38.1			35.4			31.2			28.8			24.9			24.3			
19	Adjusted Monthly PET	5.7			5			3.7			2			0.5			0			27.9
20	Infiltration Rate (in/day)	1.4			1.4			1.4			1.4			1.4			1.4			
21	I-Monthly	43			43			42			43			42			43			
22*	Total Wetland SWo	10	2	4	0	0		0	0		0			0	0		0			
	WATER BALANCE																			
23*	dS	-24	-12	-14	-3	-3		0	-1		-40			3	3		-38			
24*	S2	4	16	14	11	11		11	10		0			3	3		0			

TABLE E-11b: Water Balance Example – Solution Method (Bismarck, North Dakota)

Row	Term	January			February			March			April			May			June		
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	S1	0			0			0			0			0			0		
2*	S2-Assumed	0			0			0			0			0	10		8	5	7
3*	Savg.	0			0			0			0			0			4	2.5	3.5
4*	Aavg.(acres)	1			1			1			1			1			1.1	1.05	1.05
5*	Avg. Available S	48			48			48			48	45.5	44	48	40		44	45.5	44.5
	INFLOWS																		
6	P	0.51			0.44			0.73			1.44			2.17			3.58		
7	No. Days with P=0.5"-1.0"	0			0			0			1			1			1		
8	Avg. Watershed Qd/P(0.5-1.0)day	0.02			0.02			0.02			0.02			0.02			0.02		
9*	Avg. Wetland Qd/P(0.5-1.0)day	4			4			4			4			4			3.6	3.8	3.8
10	No. Days with P>1.0"	0			0			0			0			0			1		
11	Avg. Watershed Qd/P(1.0+)day	0.45			0.45			0.45			0.45			0.45			0.45		
12*	Avg. Wetland Qd/P(1.0+)day	90			90			90			90			90			82	86	86
13	Total Watershed Qd	0			0			0			0.2			0.2			0.47		
14*	Total Wetland Qd	0			0			0			4			4			86	90	90
	OUTFLOWS																		
15	T(degrees F)	8			10			24			42			54			64		
16	Monthly Heat Index (Dimensionless)	0			0			0			1.17			3.87			6.82		
17	Unadjusted Daily PET	0			0			0			0.04			0.08			0.12		
18	Adjustment Factor (Dimensionless)	23.1			24			30.6			34.2			39			39.6		
19	Adjusted Monthly PET	0			0			0			1.37			3.12			4.75		
20	Infiltration Rate (in/day)	1.4			1.4			1.4			1.4			1.4			1.4		
21	I-Monthly	43			40			43			42			43			42		
22*	Total Wetland SWo	0			0			0			0			0	0		38	40	41
	WATER BALANCE																		
23*	dS	-42			-40			-42			-38			-40			5	7	6
24*	S2	0			0			0			0			0			5	7	6

Notes: (1) Unless otherwise indicated, all units are in wetland (versus watershed) inches.

(2) Rows denoted with an * represent iterative (trial-and-error) parameters.

TABLE E-11b (CON'T)

Row	Term	July T1	July T2	July T3	August T1	August T2	August T3	September T1	September T2	September T3	October T1	October T2	October T3	November T1	November T2	November T3	December T1	December T2	December T3	ANNUAL
1	S1	6			3			0			0			0			0			
2*	S2-Assumed	2	4		0	11		0			0			0			0			
3*	Savg.	4	5		1.5			0			0			0			0			
4*	Aavg.(acres)	1.1	1.1		1.05			1			1			1			1			
5*	Avg. Available S	44	43		46.5			48			48			48			48			
	INFLOWS																			
6	P	2.2			1.96			1.32			0.8			0.56			0.45			16.16
7	No. Days with P=0.5"-1.0"	0			1			1			1			0			0			6
8	Avg. Watershed Qd/P(0.5-1.0)day	0.02			0.02			0.02			0.02			0.02			0.02			
9*	Avg. Wetland Qd/P(0.5-1.0)day	3.6	3.6		3.8			4			4			4	3.8		4			
10	No. Days with P>1.0"	1			0			0			0			0			0			2
11	Avg. Watershed Qd/P(1.0+)day	0.45			0.45			0.45			0.45			0.45			0.45			
12*	Avg. Wetland Qd/P(1.0+)day	82	82		86			90			90			90			90			
13	Total Watershed Qd	0.45			0.02			0.02			0.02			0			0			1.02
14*	Total Wetland Qd	82	82		3.8			4			4			0			0			
	OUTFLOWS																			
15	T(degrees F)	70			67			58			45			28			15			
16	Monthly Heat Index (Dimensionless)	8.85			7.82			4.98			1.74			0			0			35.25
17	Unadjusted Daily PET	0.14			0.13			0.09			0.04			0			0			
18	Adjustment Factor (Dimensionless)	39.9			36.6			31.5			27.9			23.4			21.9			
19	Adjusted Monthly PET	5.59			4.76			2.84			1.12			0			0			23.55
20	Infiltration Rate (in/day)	1.4			1.4			1.4			1.4			1.4			1.4			
21	I-Monthly	43			43			42			43			42			43			
22*	Total Wetland SWo	38	39		0			0			0			0			0			
	WATER BALANCE																			
23*	dS	-2	-3		-42			-40			-39			-42			-43			
24*	S2	4	3		0			0			0			0			0			

The above questions are difficult ones, since they require a statistical analysis of precipitation, which must be correlated with the runoff-producing characteristics of the wetland's tributary watershed. In our example, which follows, it can be seen that the estimated Soil Conservation Service runoff curve number (CN) for this watershed is 81. Assuming average antecedent moisture conditions (AMC), this corresponds with an initial abstraction (Ia) of approximately 0.47 inches. Since this initial abstraction must be satisfied before direct surface runoff commences, a 24-hour rainfall of approximately 0.47 inches is, under average AMC the minimum precipitation event capable of producing significant watershed runoff to replenish the wetland.

By comparison, the threshold minimum accumulation of 0.1 inches used by the National Climatic Data Center to define a "precipitation event" in its "Rainfall Event Statistics" is considerably less than this minimum runoff-producing precipitation. As a result, it can be deduced that the mean duration of the longest period between minimum 0.47-inch precipitation events is considerably longer than the 9.1 to 11.9-day range cited in the previous paragraph for minimum 0.1-inch events. Although further quantification is impossible without additional statistical analysis of precipitation data the qualitative conclusion which can be drawn from this discussion is that the "safety factor" against basin wetland dry-out in Columbus, Ohio, is not yet as great as might be inferred from a simple comparison between dry-out time and the mean dry-period duration between NCDC precipitation events. Furthermore, this discussion suggests the kind or type of additional data—not presently available—that would be needed to make a meaningful analysis of water supply dependability in basin wetlands.

Watershed characteristics can also be used to calculate the magnitude of precipitation required to fill a basin wetland from empty to pool level. The goveming equation for this analysis is:

$$P + Qdi = dS \qquad [3.5]$$

This equation reflects the fact that, during a precipitation event, and for the purpose cited above, only wetland inflows are of practical significance. For convenience, all three terms in the above equation can be expressed in units of wetland inches. Precipitation (P) is equal to the actual depth of precipitation falling directly on the wetland surface during a rainfall event. The change in storage (dS) required to raise the wetland water surface elevation from empty to pool level is 48 inches, as indicated on Figure E-33. The inflow to the wetland from direct surface runoff (Qdi) is driven by precipitation and calculated by a modified version of Equation 2.3:

Qdi = [(P-0.2S)**2/(P+0.8S)] (X) [3.6]

where,

P = precipitation (inches)
S = potential abstraction (inches)
= [(1,000/CN)-10], as per Equation 2.2
= (1,000/81)-10
= 2.35
X = factor for converting watershed inches to wetland inches
= 200 acres/1.47 acres
= 136

The conversion factor is obtained by dividing the total watershed area by the average wetland area, as indicated on Figure E-33. Substituting the above values into Equation 3.5 and solving by iteration yields a value for precipitation (P) of approximately 1.55 inches. In other words, under average antecedent moisture conditions, a 24-hour precipitation event of approximately 1.55 inches would be required to fill the example wetland from empty to pool level. If water were already stored within the wetland at the storm's commencement, a smaller magnitude storm would also fill this wetland.

Several important points should be made regarding the above discussion:

> **SUMMARY OF POINTS ON WATER SUPPLY DEPENDABILITY IN BASIN WETLANDS**
>
> • With precipitation events causing watershed runoff, wetland replenishment from direct surface runoff is usually greater than that due to precipitation falling directly on the wetland.
>
> • The ratio of direct storm runoff to precipitation (in watershed inches) is not constant; it increases with increasing storm magnitude. This variability complicates the hydrologic evaluation of wetlands.
>
> • Wet ground has a higher ratio of runoff-to-rainfall than dry ground.

- As indicated by the conversion factor (X) in the preceding paragraph, for precipitation events which are sufficient to produce watershed runoff, the degree of wetland replenishment due to direct surface runoff is usually much greater than that due to precipitation falling directly upon the wetland. Although direct precipitation will result in some level of replenishment, even during storms which are too small to produce surface runoff, this replenishment is usually insignificant compared to surface runoff.

- As previously discussed, and reinforced by the above calculations, the ratio of direct storm runoff to precipitation, expressed in terms of watershed inches, is not constant. Rather it increases with increasing storm magnitude. For example, in the Columbus, Ohio, example watershed (CN=81), a 24-hour precipitation of 0.70 inches would produce direct runoff of approximately 0.02 inches corresponding to a runoff-to-rainfall ratio of approximately 3 percent. By comparison, a 1.55-inch precipitation event would produce a runoff of approximately 0.34 inches, or a runoff-to-rainfall ratio of approximately 22 percent. This variable ratio of storm runoff to rainfall complicates the hydrologic evaluation of wetlands and necessitates a more complex analysis of precipitation data in order to develop useful statistical parameters for wetland restoration design.

- The calculations in the second point, above, and most similar hydrologic calculations, are based on the assumption of average antecedent moisture conditions (AMC). In reality, the situation is more complex, with a relatively higher ratio of runoff-to-rainfall on wet ground (i.e., above average AMC) and a relatively lower ratio on dry ground (i.e., below average AMC).

In summary, the hydrology of basin wetlands is driven directly by precipitation, which itself is a phenomenon involving random variables whose prediction is only possible in a statistical sense. The evaluation of water supply dependability within basin wetlands can be expressed generally in terms of hydroperiod variation and more specifically in terms of the probability and expected duration of basin dry-out conditions during the growing season. Determination of these parameters requires a statistical evaluation of precipitation data during extended periods of low precipitation. Although such statistical analyses **have not been performed to date**, the raw data necessary to generate them are available as long-term station precipitation records from the National Climatic Data Center. The development of necessary statistical parameters for wetland restoration design would require consideration of several important factors, including:

- The runoff-producing characteristics of the tributary watershed, particularly the magnitude (inches) of the minimum precipitation event capable of satisfying initial abstractions and producing significant watershed runoff to the wetland;

- The variable ratio of storm runoff to rainfall and the dependence of this ratio upon both watershed and precipitation characteristics; and

- The timing and sequence of precipitation events during the growing season which influence antecedent moisture conditions and the resulting runoff potential for a given rainfall event.

E.3.3.7 Applicable Experience from Farm Pond Design

One of the major problems facing wetland replacement designers is the almost complete lack of documented hydrologic design experience. This problem has several aspects:

- Compared to other hydrologically designed features (e.g., dams and reservoirs), there simply have not been many completed replacement wetlands;
- Those wetlands which have been created or restored are generally quite new and lack meaningful hydrologic validation; and
- The hydrologic design analyses associated with most existing or planned wetland replacement projects are usually quite limited or non-existent.

Given this situation, wetland replacement design must presently be performed without the singlemost valuable tool available to the designers of other hydrologic projects—a knowledge of how the "last" project has performed and how to improve upon it.

Although basic hydrologic concepts are invariant, their combination is unique in the case of wetlands. There are no other common hydrologic applications which involve the same operational conditions, evaluation requirements, or failure criteria. From this standpoint, farm ponds may be the hydrologic feature most closely related to replacement wetlands involving the design of basins. Although the design of farm ponds has never been examined or documented from a rigorous theoretical standpoint, the subject is supported by the experience gained from hundreds of thousands of existing ponds. Hamilton and Jepson (1940) compiled field observations and analyses of existing farm ponds and developed empirical relationships indicating the required minimum depths and contributing watershed areas to support these ponds. Their relationships have been adopted by the U.S. Soil Conservation Service in its (1976) Agriculture Handbook Number 590, *Ponds —Planning, Construction, Design*. Figure E-35, which is taken from this publication, indicates the approximate size drainage area required to support farm ponds of various storage capacities across the United States. Several observations can be made concerning this figure and the supporting work by Hamilton and Jepson (1940):

- The farm ponds considered in this analysis are hydrologically similar, in many respects, to basin wetlands.
- The criteria and recommended practices for successful farm pond design include minimizing evapotranspiration losses by creating maximum depth-to-area ratios and reducing unwanted vegetation growth by creating steep pond sideslopes. Obviously, these objectives differ greatly from those of replacement wetlands. However, since farm ponds designed to meet such criteria should experience lower losses than shallow, flat-sloped wetlands, it would seem reasonable to infer that Figure E-35 might be used to estimate the minimum size watershed capable of supporting basin wetlands.

One of the major problems facing wetland replacement designers is the almost complete lack of documented hydrologic design experience. Therefore, wetland replacement design must presently be performed without the single, most valuable tool available to the designers of other hydrologic projects—a knowledge of how the "last" project has performed and how to improve upon it.

- For illustrative purposes, Figure E-35 can be used to estimate the minimum required watershed area for the two potential basin wetland replacement sites in the previous water balance example. Since storage capacity of the wetlands in this example was approximately 6 acre-feet at spillway crest (Figure E-34), Figure E-35 would suggest that a minimum watershed size of approximately 25 acres in Columbus, Ohio, and approximately 180 acres in Bismarck, North Dakota, would be necessary to support a wetland in these two locations. Obviously, such empirical estimation techniques can be regarded as no more than general and preliminary design guides subject to hydrologic analysis and field verification.

E.3.4 FRAMEWORK FOR HYDROLOGIC DESIGN OF REPLACEMENT WETLANDS

Despite the known importance of hydrology to the establishment and maintenance of wetlands, and notwithstanding the growing importance and number of wetland replacement projects throughout the United States, there are currently no standardized procedures for wetland hydrologic design. In fact, for most wetland replacement projects performed to date, the level of hydrologic planning and design has been limited to a preliminary estimate of water elevation and fluctuation at the replacement site under pre-project conditions. The assumption has typically been made that these parameters, often based on rough estimates and/or one-time measurements, would remain constant after project completion. The few detailed wetland hydrologic studies which have been performed typically involve an assessment of specific existing wetland hydrologic parameters (e.g., water balance terms), rather than a projection of hydrologic conditions associated with a proposed wetland project.

Despite the known importance of hydrology to the establishment and maintenance of wetlands, there are currently no standardized procedures for wetland hydrologic design.

This lack of detailed wetland hydrologic study is understandable. As discussed in the previous section, the components of a wetland water balance are complex, interactive, stochastic, and usually very difficult to measure accurately. Also, these inflows and outflows are highly variable among different wetlands and sometimes even within the same wetland from one point in time to another. The complexity and variability of wetland hydrology make generalization very difficult and discourage the development of standard design procedures.

In some situations, replacement wetlands can succeed without thorough hydrologic analysis or real understanding of a replacement site's hydrology. For riverine and fringe wetlands (Table E-8) whose hydroperiod is largely controlled by external forces the simple water level estimation method mentioned above, combined with the assumption that existing water levels and fluctuations will remain relatively fixed after the project, and the use of biological benchmarks, may prove sufficient. However, even these type wetlands require an accurate assessment of pre-project hydroperiod and provision of adequate hydraulic capacity and controls to maintain that hydroperiod after completion of the replacement project. For basin wetlands, the task is considerably more difficult, since the hydroperiod is affected and sometimes even created, by the project itself. These basin wetlands require a considerably more detailed hydrologic assessment during design in order to provide a similar probability of success.

In some situations, replacement wetlands can succeed without thorough hydrologic analysis or real understanding of a replacement site's hydrology.

A common, consistent approach to replacement wetland hydrologic design is needed but is presently lacking. Unfortunately, the current state of wetland hydrology science and practice is not sufficiently advanced for the establishment of specific design procedures and standards. However, it is possible to develop a generalized procedure, or framework, for this design process, using the basic hydrologic concepts and methods discussed previously. This section offers one possibility for such a design process framework. Its principal components, shown on Figure E-36 and discussed briefly in the following sections, are as follows:

- **Step 1:** Establish the hydrologic position of a replacement site within the watershed, i.e., the hydrogeologic and geomorphologic relationship between the proposed wetland site and the larger hydrologic unit of which it is a part.
- **Step 2:** Evaluate baseline (i.e., pre-project) water surface elevations (WSELs) and WSEL fluctuations at the replacement site.
- **Step 3:** Estimate the post-project hydroperiod(s) of the wetland.
- **Step 4:** Prepare topographic, hydraulic, and engineering design of the replacement wetland.

E.3.4.1 Establishing Hydrologic Position within the Watershed

Successful hydrologic design of replacement wetlands depends first and foremost upon establishing the relationship which exists between the replacement site and the larger hydrologic unit (i.e., watershed) of which it is a part. Too often, wetland hydrology studies when performed at all tend to focus upon the wetland as a separate, independent unit. In reality, the hydrologic relationship between the wetland and its supporting watershed, and the corresponding reaction between the two may have a dominating effect upon wetland behavior. This is especially true in the case of riverine and fringe wetlands, but it also applies in a more limited way to basin wetlands. Ideally, site selection may eliminate the need for water balance and hydroperiod studies if it can be confirmed on the basis of secondary and field observations that reliable hydrology exists. As implied earlier and noted in Chapter 2, wetland replacement sites located next to lakes, large ponds, and major rivers offer potentially optimum sites. Once the WSELs become more variable, then it will be necessary to think in terms of creating a basin system to control water elevations to meet the goals and objectives of the replacement wetland.

The basic requirement at this level of the design process is to identify the physical position of the wetland replacement site in relationship to underlying groundwater and nearby or adjacent surface water bodies. The three-category classification system indicated in Table E-8 is useful for this purpose, although regional experience might dictate the need for an alternate or more refined definition of hydrologic position. Regardless of classification or terminology, however, it is important at this initial stage of the design process to:

- Identify the general position of the wetland replacement site within the watershed;
- Establish the location of any permanent or stable surface waters which might influence the water levels (hydroperiod) within the wetland;
- Estimate the depth to the water table and the probable direction of shallow groundwater flow at the site;
- Evaluate the relative magnitude of the drainage area tributary to the wetland versus the drainage area tributary to any adjacent, permanent surface water bodies; and
- Determine which will be the primary hydrologic inflows to and outflows from the wetland.

Successful hydrologic design of replacement wetlands depends, first and foremost, upon establishing the relationship which exists between the replacement site and the larger hydrologic unit (i.e., watershed) of which it is a part.

E.3.4.2 Evaluating Baseline Water Surface Elevations (WSELs) and WSEL Fluctuations

- **For riverine and fringe wetlands:** This step involves obtaining and reviewing hydrologic data for the river, lake, ocean, etc. which lies adjacent to the proposed site and locating biological benchmarks which meet the criteria described in Chapter 2. Some form of hydrologic data are almost always available for this purpose, although extrapolation from it may be required depending upon the position of the replacement site. For example, for tidal wetlands, the annual tide tables published by the U.S. National Ocean Service (NOS) can provide very accurate information concerning baseline water surface elevations (WSELs) and fluctuations. For inland lakes and reservoirs, periodic or continuous water level records may be maintained by various agencies or municipalities. (For example, the U.S. Army Corps of Engineers, Detroit District, publishes a monthly summary of historical, current, and projected future water levels for each of the Great Lakes.) Streamflow records, including discharges and water levels (via rating curves), are available from the U.S. Geological Survey. In the case of riverine wetlands, however, these streamflow data will usually provide only a starting point for the extrapolation of hydroperiod back to a particular (probably ungaged) wetland replacement site.
- **For all wetlands, but especially basin wetlands:** It is also important to evaluate the level and fluctuation of groundwater at a proposed replacement site. Although preliminary estimates can be made on the basis of topography and nearby surface water levels, groundwater monitoring is usually required for basin wetlands which are anticipated to intercept the water table or to be supported by groundwater flow. Groundwater monitoring in such situations is usually performed using shallow piezometers, as discussed previously. Although analytical estimates of groundwater levels using such methods as the Dupuit-Forchheimer relationship (Equation 2.9) cannot be expected to

substitute for actual monitoring results, they are an important and useful tool for developing and interpreting a monitoring program as well as reducing the amount of field data which needs to be collected.

In estimating the water level and water level fluctuation at ungaged sites, it is often helpful to keep the "backwater" principle, discussed in Section E.2.6.3.3, in mind. This concept, developed for surface water profile analysis along stream channels, involves the progressive calculation of water levels in an upstream direction, starting at a known or calculated downstream WSEL. It applies equally well to the estimation of groundwater profiles discharging into a surface water body, as illustrated in Figure E-31. The concept can be important in this stage of the wetland design process because the estimation of baseline WSELs and WSEL fluctuations often requires the extrapolation of hydrologic data from known locations which are downgradient or downstream from the proposed replacement site.

E.3.4.3 Estimating the Post-project Hydroperiod

The baseline water surface elevations (WSELs) and WSEL fluctuations for riverine and fringe wetlands, through proper hydraulic design, can generally be maintained after the construction of a replacement wetland. When they are, the baseline conditions and the post-project hydroperiod are essentially identical. For replacement basin wetlands, however, there may be no baseline condition if the replacement site was not a water body previously. Even if it was, the chances are that the wetland itself will have a significant effect upon the hydroperiod. Therefore, basin wetlands usually require the performance of water balance analyses to estimate their post-project hydroperiods. An example of a water balance analysis for a basin wetland was provided in Section E.3.3.5.

E.3.4.4 Designing Replacement Wetlands

Even when the hydrology of a watershed is sufficient to support a wetland and the hydroperiod can be reasonably estimated, the success of a replacement project depends upon proper engineering design, particularly hydraulic design. Hydrology establishes the supply and availability of water to a wetland, but it does not guarantee free water movement into or out of the site. Even riverine and fringe wetlands whose **potential** hydroperiods are largely a function of the water levels in adjacent surface water bodies may be isolated to some degree from these supporting hydroperiods if their hydraulic inlet or outlet capacity is limited. In some cases, hydraulic structures may be used to "throttle" this inflow or outflow intentionally, such as in the case of a riverine wetland with outlet works whose capacity is set to release water slowly and thereby maintain higher wetland water levels after the river levels have subsided to base flow conditions. In other cases, the throttling effect might be unintentional and might act to starve the wetland from a needed and available supply of outside water or to limit its release from a wetland at a time when drawdown is desirable for functional reasons (e.g., flood desynchronization). There are a myriad of possible hydraulic design objectives and methods related to wetlands. Although they cannot be generalized, it is always important that they be addressed in the wetland replacement process.

E.4 REFERENCES CITED

Bardecki, M.J. 1987. Cumulative impacts of agricultural land drainage on watershed hydrology. In: Proceedings: National Wetland Symposium, Wetland Hydrology. Association of State Wetland Managers, Inc., Sep. 16-18, 1987, Chicago, IL.

Beard, L.R. 1962. Statistical methods in hydrology. U.S. Army Corps of Engineers, Sacramento, CA. 62 pp.

Bianchi, W.C. and E.E. Haskell, Jr. 1966. Air release in the vadose zone as it affects water movements beneath a recharge basin. Water Resources Research, 2:315-322.

Blaney, H.G. and W.D. Criddle. 1950. Determining water requirements in irrigated areas from climatological and irrigation data. U.S. Soil Conservation Service, Tech. Pap. 96.

Brinson, M.B. 1986. Strategies for assessing the cumulative effects of wetland alteration on water quality. Environmental Management, 12(5).

Broadfoot, W.M. and H.L. Williston. 1973. Flooding effects on southern forests. J. Forestry 71(9):584-587.

Carter, V., M.S. Bedlinger, R.P. Novitzke and W.O. Wilen. 1978. Water resources and wetlands (theme paper), pp. 344-376. In: Wetland Functions and Values: The State of Our Understanding. American Water Resources Association.

Cedergren, H.R. 1977. Seepage, Drainage, and Flow Nets. John Wiley & Sons, New York, NY. 534 pp.

Chow, V.T. 1964. Handbook of Applied Hydrology. McGraw-Hill Book Co., New York, NY, 29 sections.

Chow, V.T. 1959. Open-Channel Hydraulics. McGraw-Hill Book Co., New York, NY. 680 pp.

Chu, C.S. and C.E. Bower. 1977. Computer programs in water resources. University of Minnesota, Minneapolis, MN, WRRC bull. 97.

Cowardin, L.M., V. Carter, F.C. Golet and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service Publication FWS/OBS-79/31, Washington, D.C., 103 pp.

Dalton, J. 1802. Experimental essays on the constitution of mixed gases; on the force of steam or vapor from water and other liquids in different temperatures, both in a Torricellian vacuum and in air; on evaporation; and on the expansion of gases by heat. Manchester Lit. Phil. Soc. Mem. Proc., 5:536-602.

Davis, S.N. 1969. Porosity and permeability of natural materials, pp. 54-89. In: Flow Through Porous Media, DeWiest, R.J.M (ed.), Academic Press, New York, NY.

Dean, R.G. 1966. Tides and harmonic analysis, Chapter 4. In: Estuary and Coastline Hydrodynamics, Ippen, A.T., McGraw-Hill Book Co., New York, NY.

DeWiest, R.G.M. 1965. Geohydrology. John Wiley & Sons, Inc., New York, NY. 366 pp.

Driscoll, F.G. 1986. Groundwater and Wells. Johnson Filtration Systems, Inc., St. Paul, MN. 1089 pp.

Fetter, C.W. 1980. Applied Hydrogeology. Merrill Publishing Company, Columbus, OH. 488 pp.

Freeze, R.A. and P.A. Witherspoon. 1967. Theoretical analysis of regional groundwater flow: 2. Effect of water-table configuration and subsurface permeability variation. Water Resources Research, 3(2):623-634.

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

Gilman, C.S. 1964. Rainfall, Section 9. In: Handbook of Applied Hydrology, Chow, V.T. (ed.), McGraw-Hill Book Co., New York, NY.

Hamilton, C.L. and H.G. Jepson. 1940. Stock-water developments: wells, springs and ponds. U.S. Department of Agriculture, Farmers Bull. 1859.

Heimburg, K. 1984. Hydrology of north-central Florida cypress domes, pp. 72-82. In: Cypress Swamps, Ewel, K.C. and H.T. Odum (eds.), University Presses of Florida, Gainsville, FL.

Hemond, H.F. 1982. A low-cost multichannel recording piezometer system for wetland research. Water Resources Research, 18(1):182-186.

Hillel, D. 1971. Soil and Water, Physical Principles and Processes. Academic Press, New York, NY. 288 pp.

Hollands, G.G. 1987. Assessing the relationship of groundwater and wetlands. In: Proceedings: National Wetland Symposium, Wetland Hydrology. Association of State Wetland Managers, Inc., September 16-18, 1987, Chicago, IL.

Hudson, H.E., Jr. and R. Hazen. 1964. Droughts and low streamflow, Section 18. In: Handbook of Applied Hydrology, Chow, V.T. (ed.), McGraw-Hill Book Co., New York, NY.

Ippen, A.T. and D.R.F. Harleman. 1966. Tidal dynamics in estuaries, Chapter 10. In: Estuary and Coastline Hydrodynamics, Ippen, A.T., McGraw-Hill Book Co., New York, NY.

Johnson, P.B. 1987. Use of wetlands in stormwater management: a case example of local government involvement, pp. 223-229. In: Proceedings: National Wetland Symposium, Wetland Hydrology. Association of State Wetland Managers, Inc., Sep. 16-18, 1987, Chicago, IL.

Kadlek, J.A. 1983. Water budgets for small diked marshes. Water Resources Bulletin, 19(2):223-229.

Kohler, M.A., T.J. Nordenson, and D.R. Baker. 1959. Evaporation maps for the United States. U.S. Weather Bureau Technical Paper 37.

Kuichling, E. 1889. The relation between the rainfall and the discharge of sewers in populous districts. Trans. Am. Soc. Civ. Engrs., 20:1-56.

Kusler, J. 1987. Hydrology: An introduction for wetland managers. In: Proceedings: National Wetland Symposium, Wetland Hydrology. Association of State Wetland Managers, Inc., Sep. 16-18, 1987, Chicago, IL.

LaBaugh, J.W. 1986. Wetland ecosystem studies from a hydrologic perspective. Water Resources Bulletin, 22(84065).

Lambe, T.W. 1951. Soil Testing for Engineers. John Wiley & Sons, Inc., New York, NY. 165 pp.

Langbein, W.B et al., 1949. Annual runoff in the United States. U.S. Geological Survey, Circular 52.

Lee, D.R. 1977. A device for measuring seepage flux in lakes and estuaries. Limnology and Oceanography, 22(1):140-147.

Linsley, R.K. and J.B. Franzini. 1972. Water-Resources Engineering. McGraw-Hill Book Co., New York, NY. 690 pp.

Linsley, R.K., M.A. Kohler, and J.L.H. Paulhus. 1982. Hydrology for Engineers. McGraw-Hill Book Co., New York, NY. 508 pp.

Lowry, R.L. and A.F. Johnson. 1942. Consumptive use of water for agriculture. Trans. Am. Soc. Civ. Engrs., 107:1252.

Mather, J.R. 1981. Using computed stream flow in watershed analysis. Water Resources Bulletin, 17(3):474-481.

McPherson, M.B. 1974. Some notes on the rational method of storm drain design. ASCE Urban Water Resources Research Program, Technical Memorandum No. 6.

Meyboom, P. 1966. Unsteady groundwater flow near a willow ring in hummocky moraine. Journal of Hydrology, 4:38-62.

Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold, New York, NY. 539 pp.

Morris, H.M. 1963. Applied Hydraulics in Engineering. The Ronald Press Co., New York, NY. 455 pp.

Musgrave, C.W. and H.N. Holtan. 1964. Infiltration, Section 12. In: Handbook of Applied Hydrology, Chow, V.T. (ed.), McGraw-Hill Book Co., New York, NY.

Novitzki, R.R. 1979. The hydrologic characteristics of Wisconsin's wetlands and their influence on floods, streamflow, and sediment. Paper presented at the National Symposium on Wetlands, November 6-10, 1978, Lake Buena Vista, FL.

Penman, H.L. 1948. Natural evaporation from open water, bare soil, and grass. Proc. Roy. Soc. London, ser. A, 193:120-145.

Priestly, C.H.B. and R.J. Taylor. 1972. On the assessment of surface heat flux and evaporation using large scale parameters. Mon. Weather Rev., 100:81-92.

Rawls, W.J., D.L. Brakensiek and K.E. Saxton. 1982. Estimation of soil water properties. Trans. Am. Soc. Agricultural Engrs., 1316-1320 and 1328.

Schroeder, P.R., A.C. Gibson, and M.D. Smolen. 1984. The hydrologic evaluation of landfill performance (HELP) model, Volume II, Documentation for Version 1. Prepared for U.S. Environmental Protection Agency, EPA/530-SW-84-010.

Sherman, L.K. 1932. Streamflow from rainfall by the unit-graph method. Engineering News Record, 108:501-505.

Sourballe, N.C. 1987. Hydrologic regime of a floodplain wetland in Massachusetts. In: Proceedings: National Wetland Symposium, Wetland Hydrology. Association of State Wetland Managers, Inc., Sep. 16-18, 1987, Chicago, IL.

Steurer, P.M. and A. Nold. 1986. Climatic Data Summaries from Hourly Precipitation Data and State Climatic Divisions. National Climatic Data Center. Rainfall Event Statistics.

Thornwaite, C.W. 1946. The moisture factor in climate. Trans. Am. Geophys. Union, 27:41-48.

Thornwaite, C.W. and J.R. Mather. 1955. The water balance. Drexel Institute of Technology, Publications in Climatology, VIII(1).

Thornwaite, C.W. and J.R. Mather. 1957. Instructions and tables for computing potential evapotranspiration and the water balance. Drexel Institute of Technology, Publications in Climatology, X(3).

Todd, D.K. 1964. Groundwater, Section 13. In: Handbook of Applied Hydrology, Chow, V.T. (ed.), McGraw-Hill Book Co., New York, NY.

Toth, J. 1963. A theoretical analysis of groundwater flow in small drainage basins. Journal of Geophysical Research, 68:4795-4812.

U.S. Army Corps of Engineers. 1959. Backwater curves in river channels. Manual EM 1110-2-1409, 57 pp.

U.S. Army Corps of Engineers. 1975. Hydrologic frequency analysis. Hydrologic Engineering Center, Davis, CA.

U.S. Army Corps of Engineers. 1976. HEC-2 water surface profiles, users manual. Hydrologic Engineering Center, Computer Program 723-X6-L202A.

U.S. Army Corps of Engineers. 1987. Corps of Engineers Wetland Delineation Manual. Technical Report Y-87-1, Waterways Experiment Station, Vicksburg, MS. 98 pp.

U.S. Bureau of Public Roads. 1965. Hydraulic charts for the selection of highway culverts. Hydraulics Branch, Bridge Division, Office of Engineering and Operations, Hydraulic Engineering Circular 5.

U.S. Department of Health, Education and Welfare. 1957. Manual of Septic Tank Practice. Public Health Service Publication 526. 93 pp.

U.S. Environmental Protection Agency. 1986. RCRA ground-water monitoring technical enforcement guidance document. Office of Solid Waste and Emergency Response, OSWER-9950.1. 208 pp.

U.S. Federal Highway Administration. 1984. Hydrology. Hydraulic Engineering Circular No. 19, FHWA-1P-84-15, McLean, VA. 342 pp.

U.S. Geological Survey. 1970. The National Atlas of the United States of America. Washington, D.C. 417 pp.

U.S. Geological Survey. 1986. Ground water. Popular publications of the U.S. Geological Survey, 1986-491-402/04.

U.S. Geological Survey. 1990. Water resources data, Ohio, water year 1989. Volumes 1 and 2, Water Data Reports OH-89-1 and OH-89-2. 226 pp. and 309 pp.

U.S. National Oceanic and Atmospheric Administration. 1978. Climatography of the United States No. 90. National Climatic Data Center, Asheville, NC.

U.S. National Oceanic and Atmospheric Administration. 1980. Comparative climatic data for the United States through 1979. National Climatic Data Center, Asheville, NC.

U.S. Soil Conservation Service. 1973. A method for estimating volume and rate of runoff in small watersheds. SCS-TP-149.

U.S. Soil Conservation Service. 1976. Ponds—planning, design, construction. Agriculture Handbook Number 590.

U.S. Soil Conservation Service. 1983. Computer program for project formulation—hydrology. SCS Technical Release 20, Washington, D.C.

U.S. Soil Conservation Service. 1985. National Engineering Handbook—Section 4—Hydrology. Washington, D.C.

U.S. Soil Conservation Service. 1986. Urban hydrology for small watersheds—Technical Release No. 55, Washington, D.C.

U.S. Weather Bureau. 1961. Rainfall frequency atlas for the United States. Technical Paper 40.

U.S. Weather Bureau. 1968. Climatic Atlas of the United States. Washington, D.C.

Veihmeyer, F.J. 1964. Evapotranspiration, Section 11. In: Handbook of Applied Hydrology, Chow, V.T. (ed.), McGraw-Hill Book Co., New York, NY.

Velz, C.J. and J.J. Gannon. 1960. Drought flow characteristics of Michigan streams. Water Resources Commission of the State of Michigan, Lansing, MI.

Verry, E.S. and D.H. Boelter. 1978. Peatland hydrology, pp. 389-402. In: Wetland Functions and Values: The State of our Understanding, American Water Resources Association.

Walton, W.C. 1970. Groundwater Resource Evaluation. McGraw-Hill Book Co., New York, NY. 664 pp.

Wang, H.F. and M.P. Anderson. 1982. Introduction to Groundwater Modeling. W.H. Freeman and Company, San Francisco, CA. 237 pp.

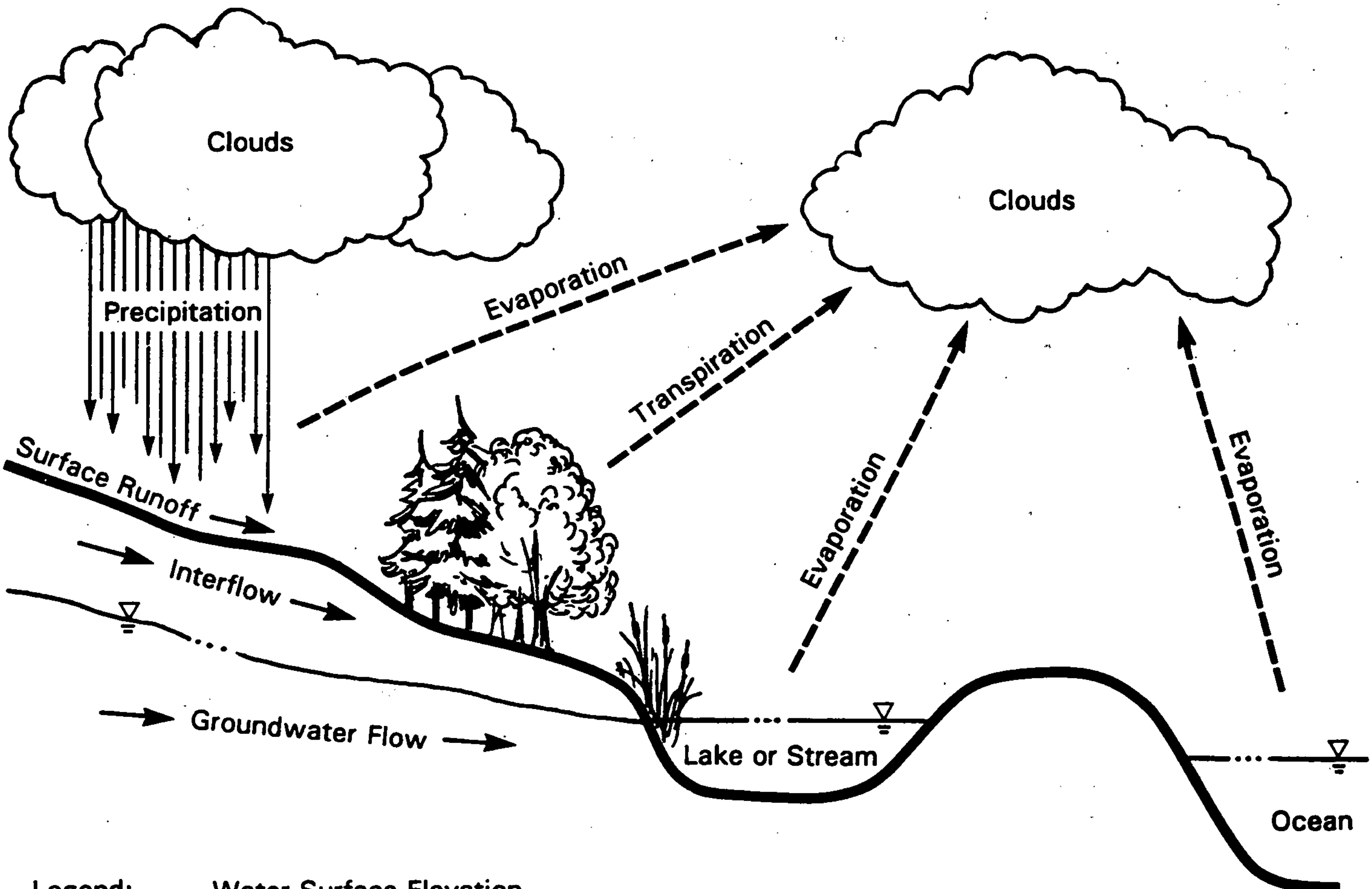
Winter, T.C. 1976. Numerical simulation analysis of the interaction of lakes and groundwater. U.S. Geological Survey, Professional Paper 1001, Washington, D.C.

Winter, T.C. 1981. Uncertainties in estimating the water balance of lakes, pp. 82-112. Water Resources Bulletin, 17(1).

Winter, T.C. 1988. A conceptual framework for assessing cumulative impacts on the hydrology of nontidal wetlands. Environmental Management, 12(5):605-620.

Yevdjevich, V.M. 1964. Statistical and probability analysis of hydrologic data: Part II: Regression and correlation analysis, Sections 8-11. In: Handbook of Applied Hydrology, Chow, V.T. (ed.), McGraw-Hill Book Co., New York, NY.

Zimmerman, J.H. 1987. A multi-purpose wetland characterization procedure, featuring the hydroperiod. In: Proceedings: National Wetland Symposium, Wetland Hydrology. Association of State Wetland Managers, Inc., Sep. 16-18, 1987, Chicago, IL.



Legend: Water Surface Elevation

Notes:
(1) Total Runoff = Surface Runoff + Interflow + Groundwater Flow
Direct Runoff = Surface Runoff + Interflow
Base Flow = Groundwater Flow

FIGURE E-1

The Hydrologic Cycle

Station	Thiessen Polygon Area (sq. mi.)	Precipitation (in.)	Product (in.–sq. mi.)
A	13	1.40	18.2
B	20	2.09	41.8
C	6	1.32	7.9
D	7	2.87	20.1
E	38	2.41	91.6
F	14	2.92	40.9
G	2	3.30	6.6
Total	10		227.1

$$\text{Average Precipitation} = \frac{227.1}{100} = 2.27 \text{ in.}$$

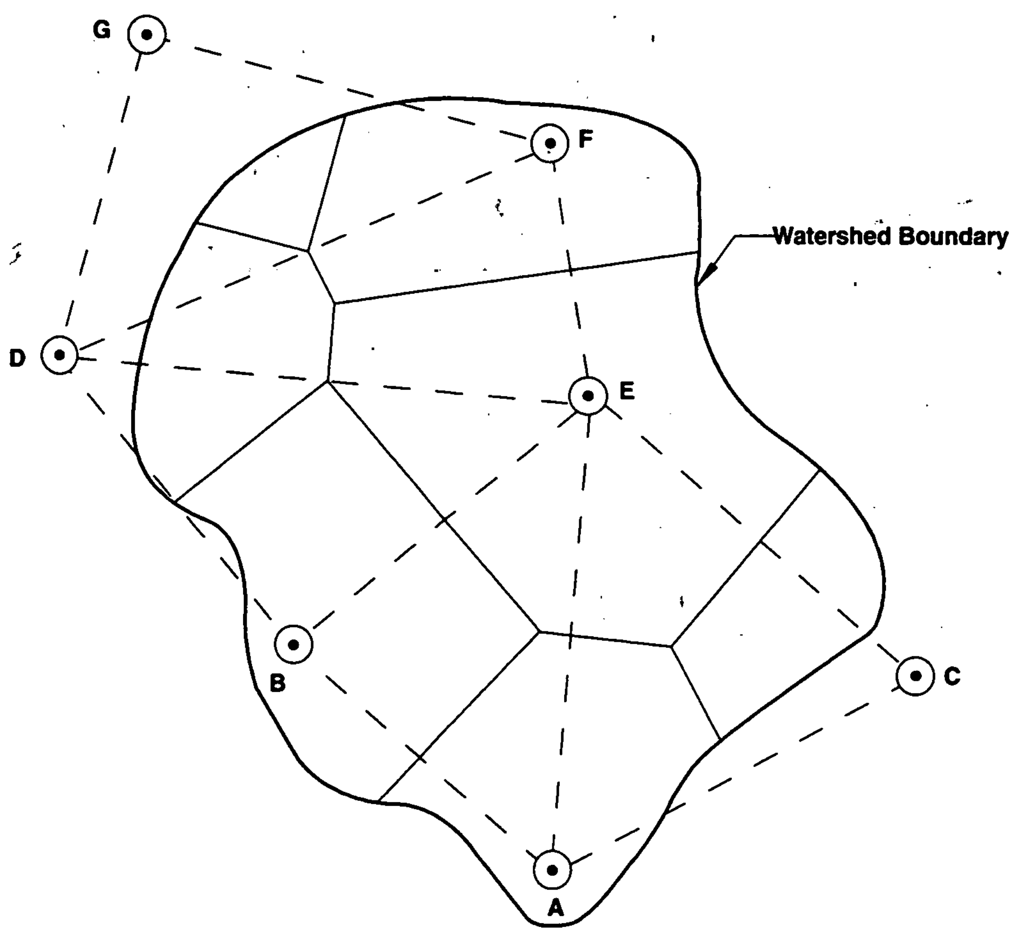


FIGURE E-2

Thiessen Polygon Method for Determining Average Precipitation

Isohyet (in.)	Watershed Area Between Isohyets (sq. mi.)	Average Precipitation (in.)	Product (in.–sq. mi.)
1.0			
	3	1.25	3.8
1.5			
	25	1.75	43.8
2.0			
	39	2.25	87.8
2.5			
	29	2.75	79.8
3.0			
	4	3.25	13.0
3.5			
Total	100		228.2

$$\text{Average Precipitation} = \frac{228.2}{100} = 2.28 \text{ in.}$$

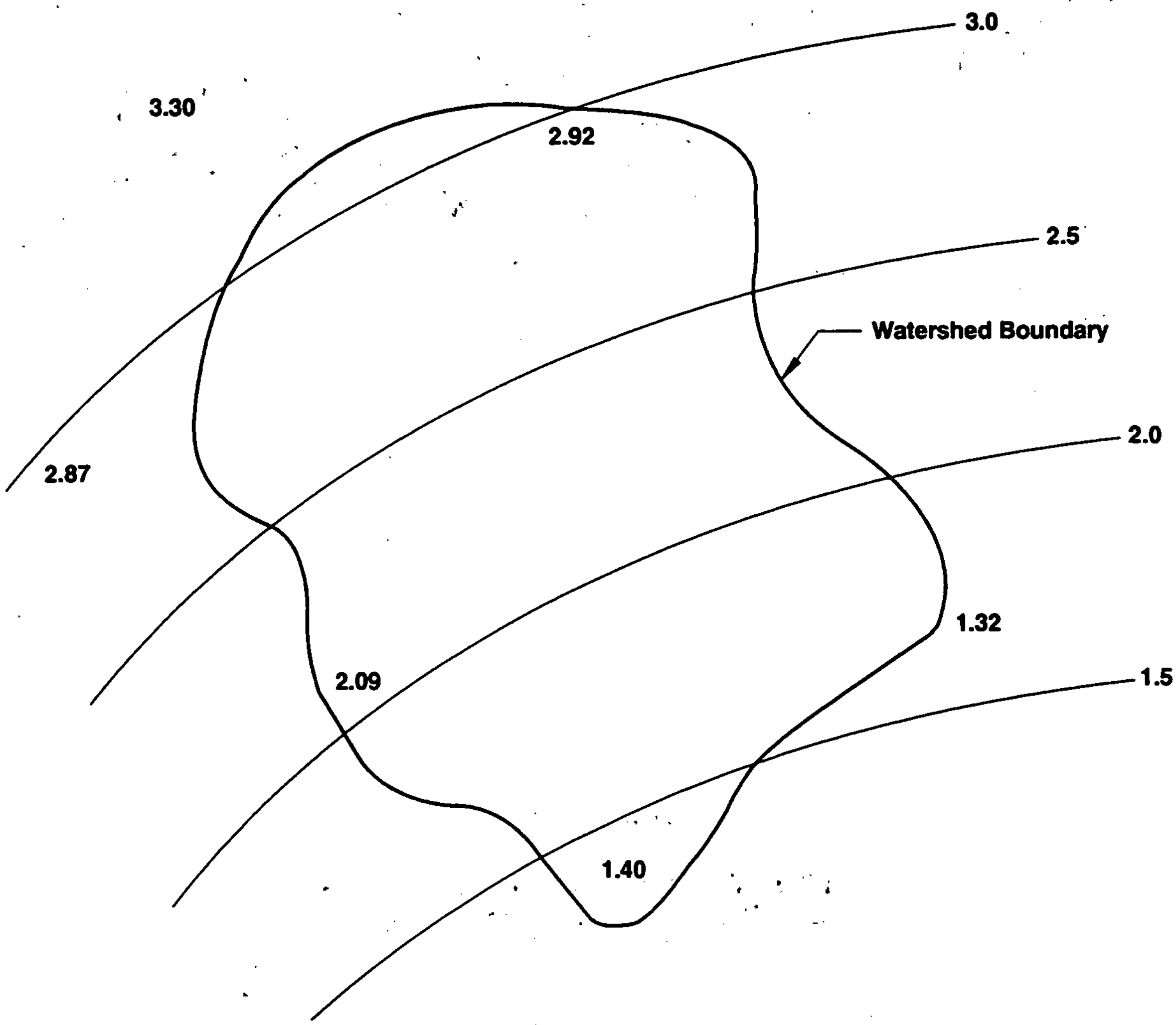


FIGURE E-3

Isohyetal Method for Determining Average Precipitation

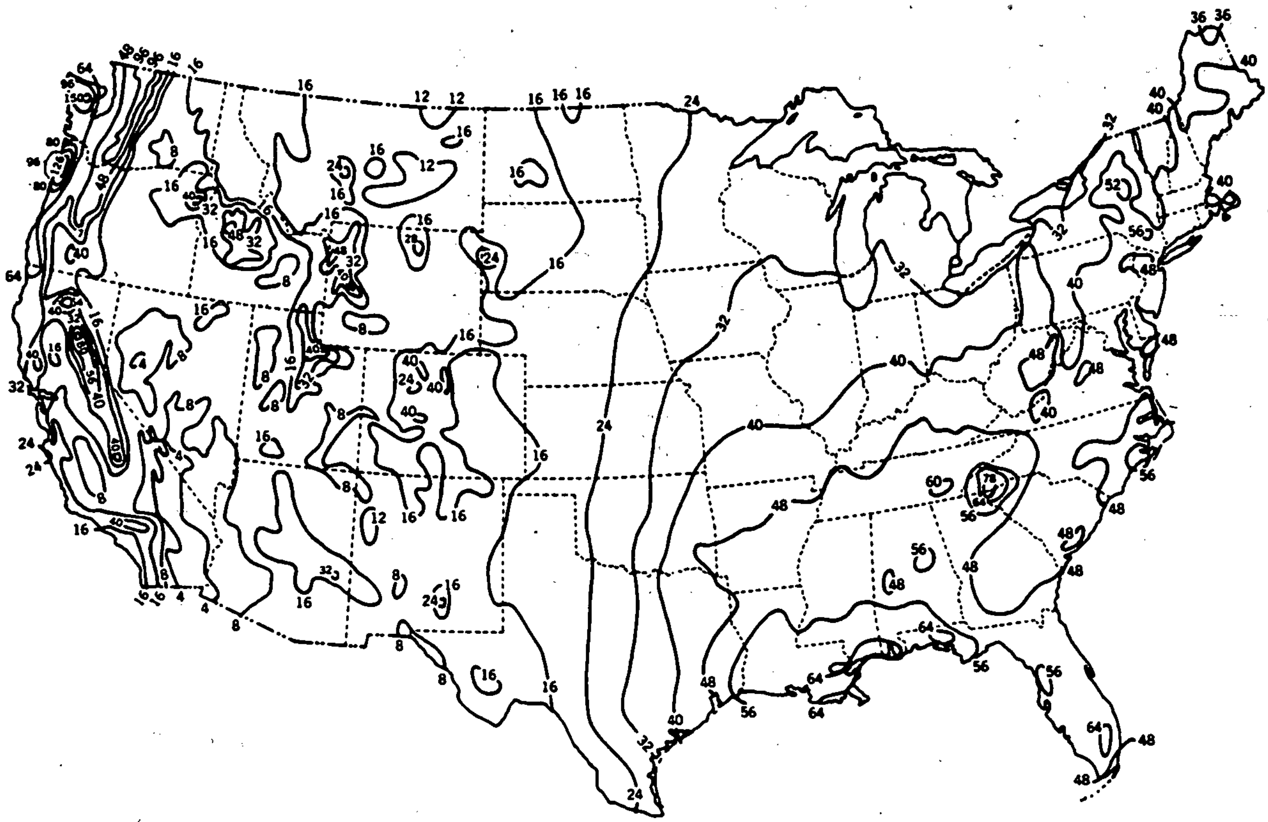


FIGURE E-4

Mean Annual Precipitation in the United States (after United States Weather Bureau)

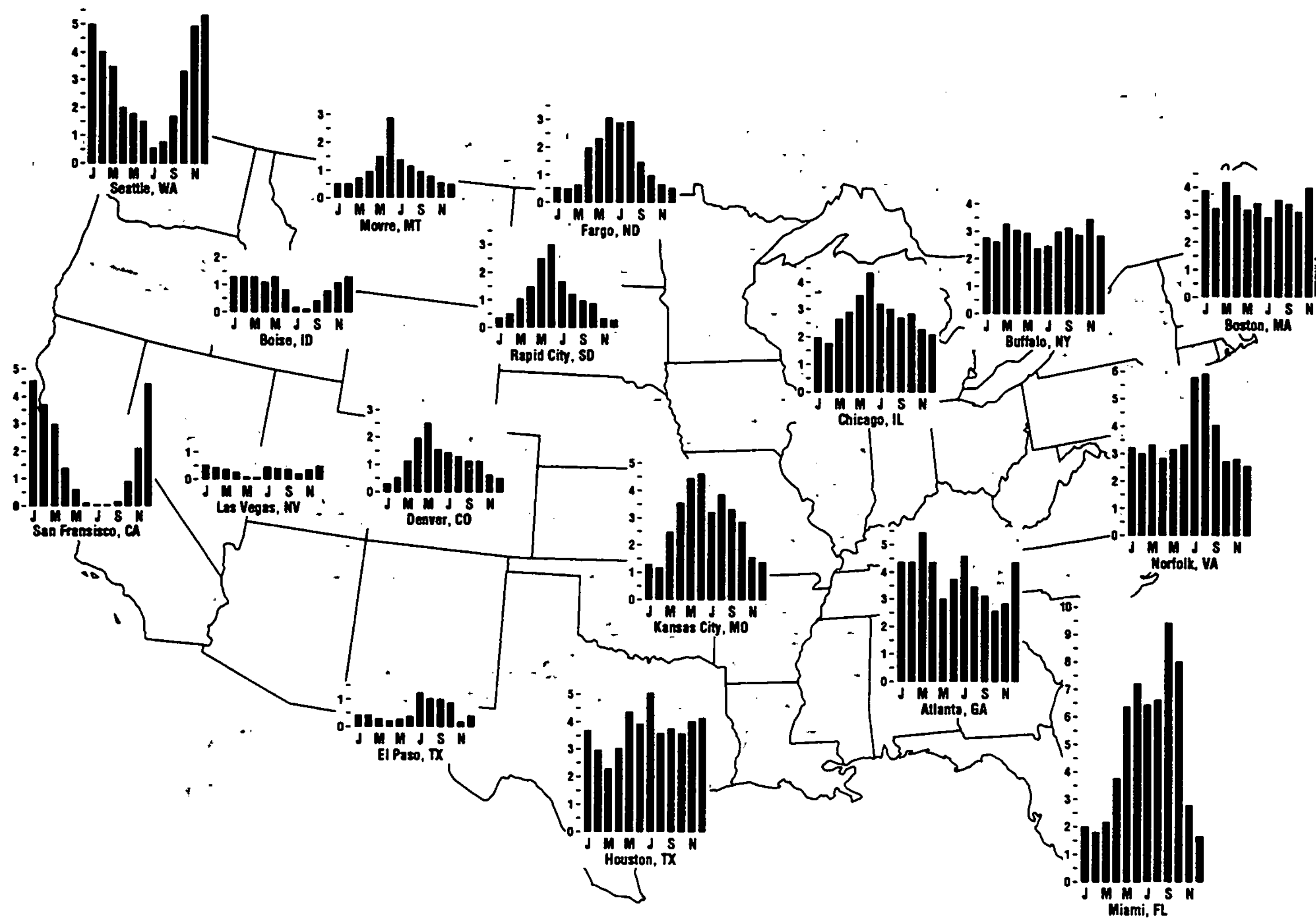


FIGURE E-5

Monthly Variation of Precipitation in the United States (inches)
(U.S. Environmental Data Service)

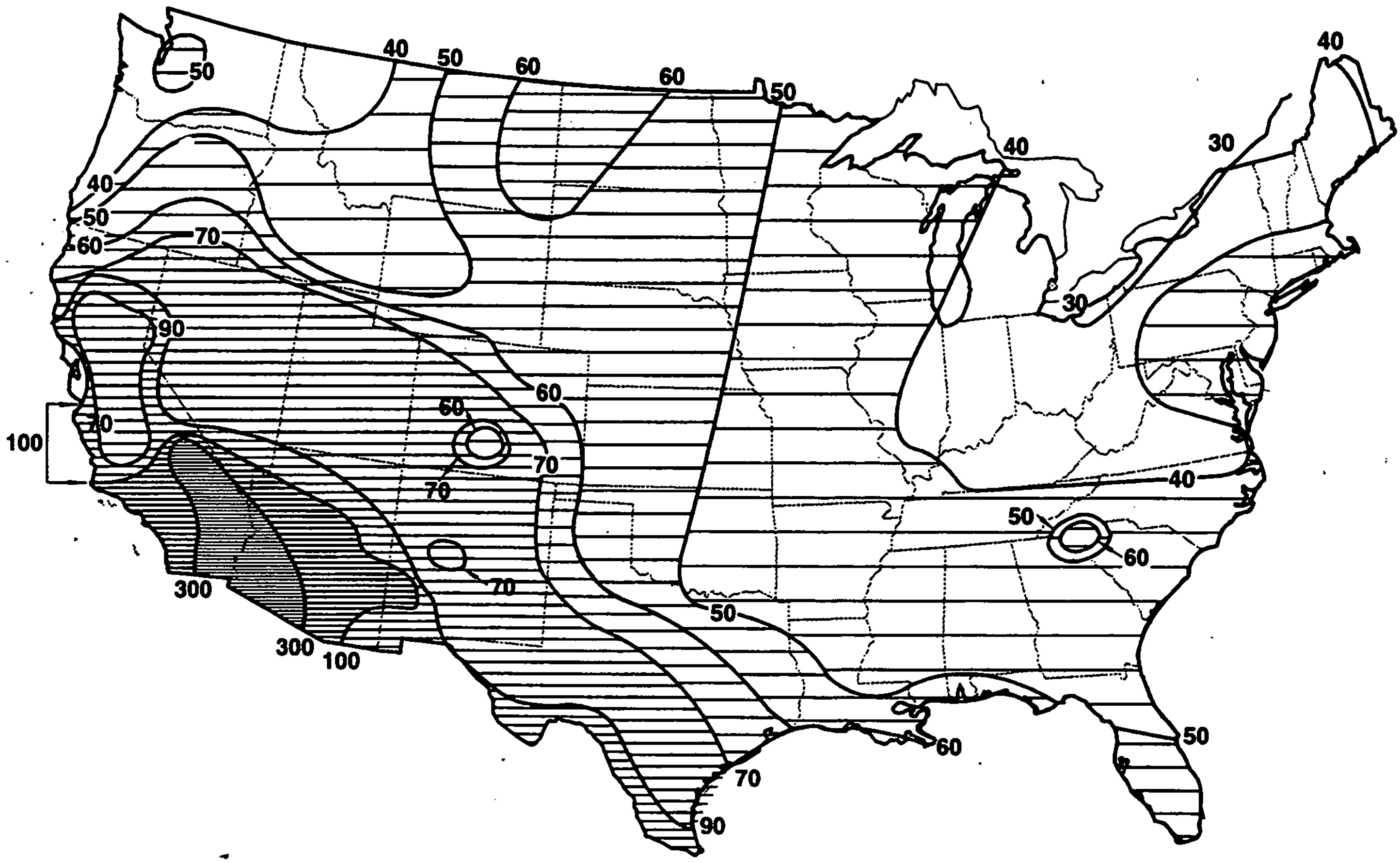


FIGURE E-6

Percentage Deviation from Mean Annual Precipitation Occurring in Three-fourths (75%) of the Years (one-eighth are wetter, one-eighth are drier) (After Visher)

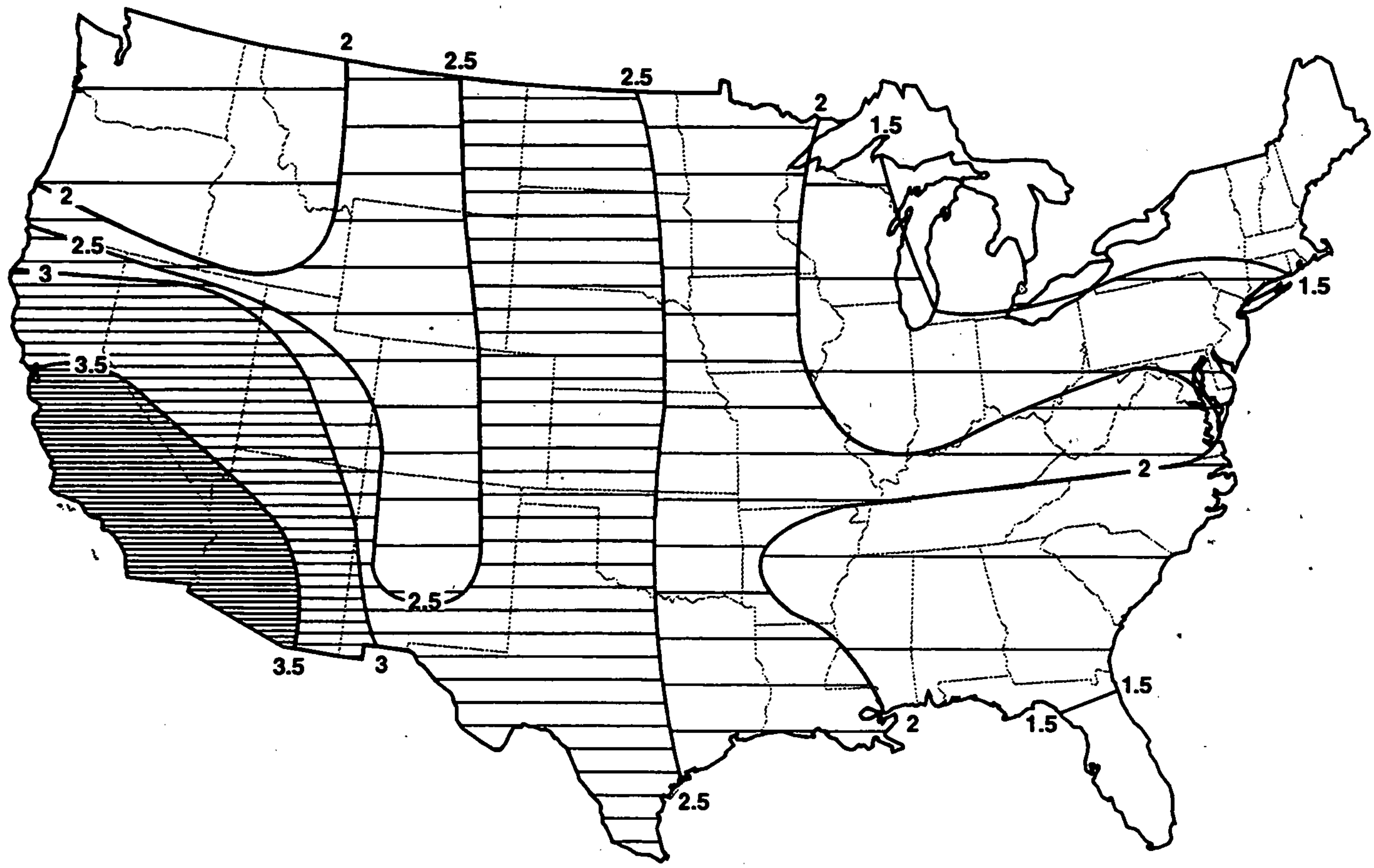


FIGURE E-7

Ratio of Precipitation of the Wettest to That of the Driest Year (after Visher)

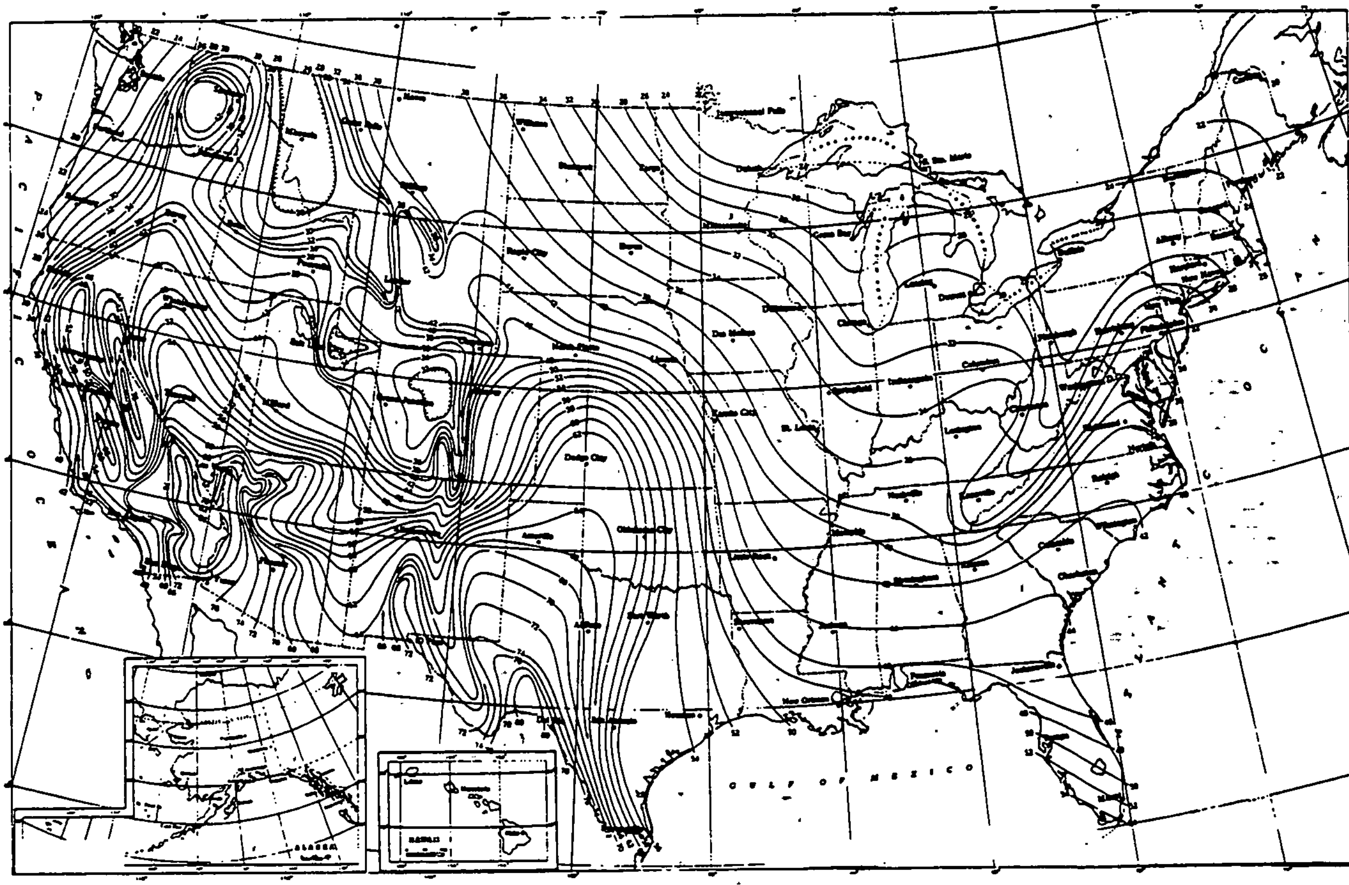


FIGURE E-8

Mean Annual Lake Evaporation in the United States (inches)
(after Kohler et al. 1959)

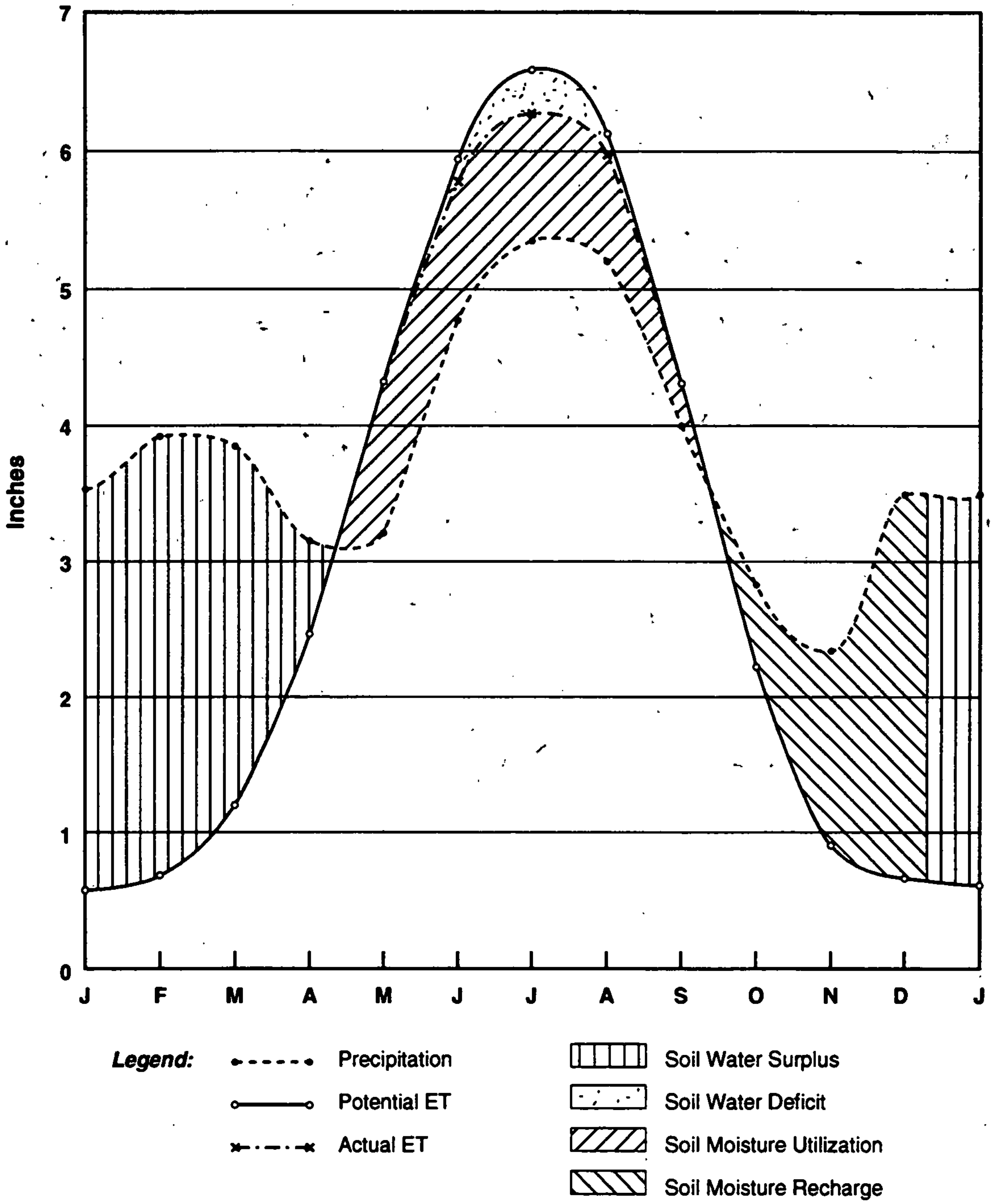


FIGURE E-9

Relationship Among Precipitation, Potential Evapotranspiration, and Actual Evaporation (after Thornwaite and Mather 1955)

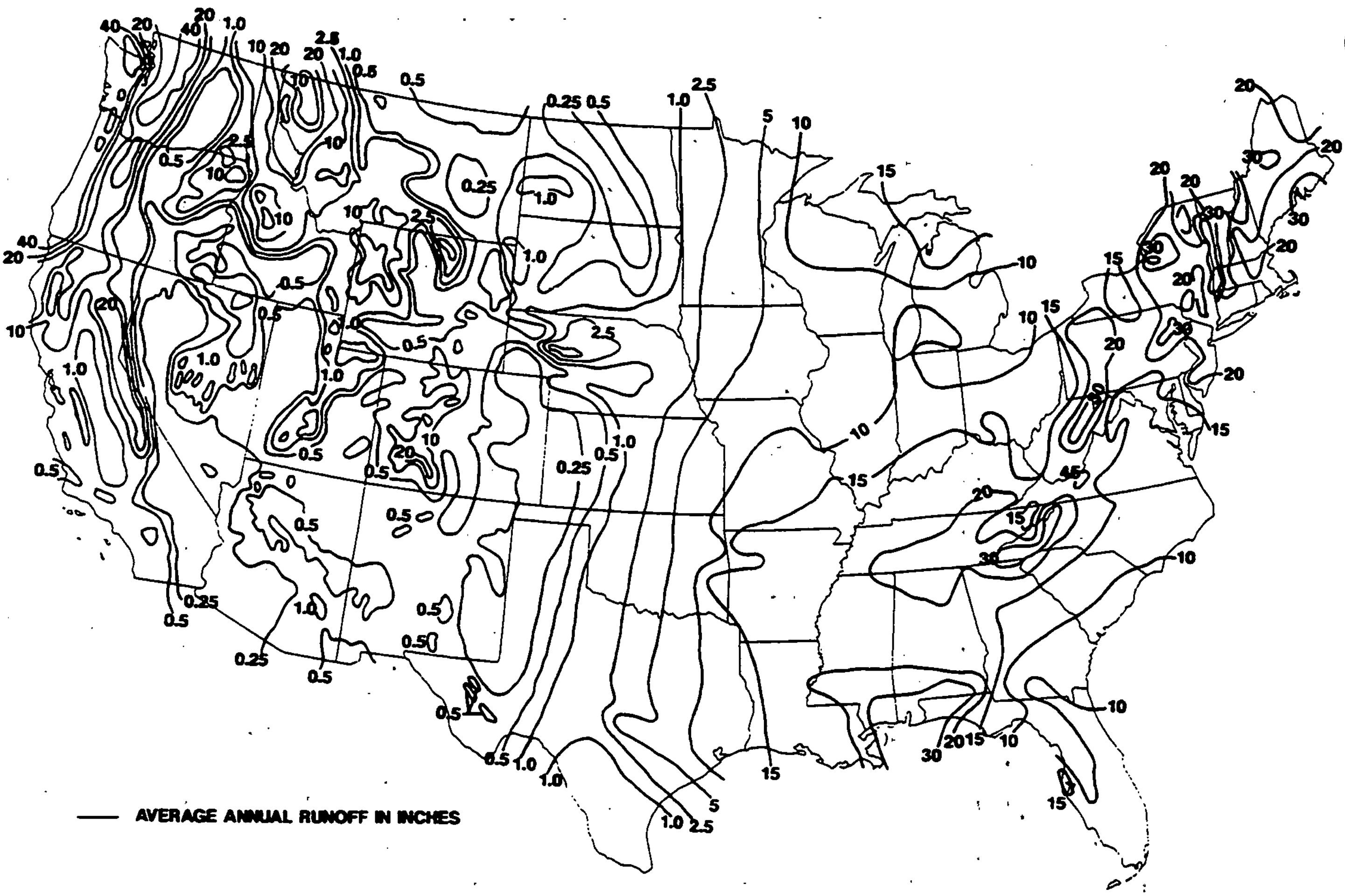


FIGURE E-10

Mean Annual Total Runoff in the United States (inches)
(after Langbein et al. 1949)

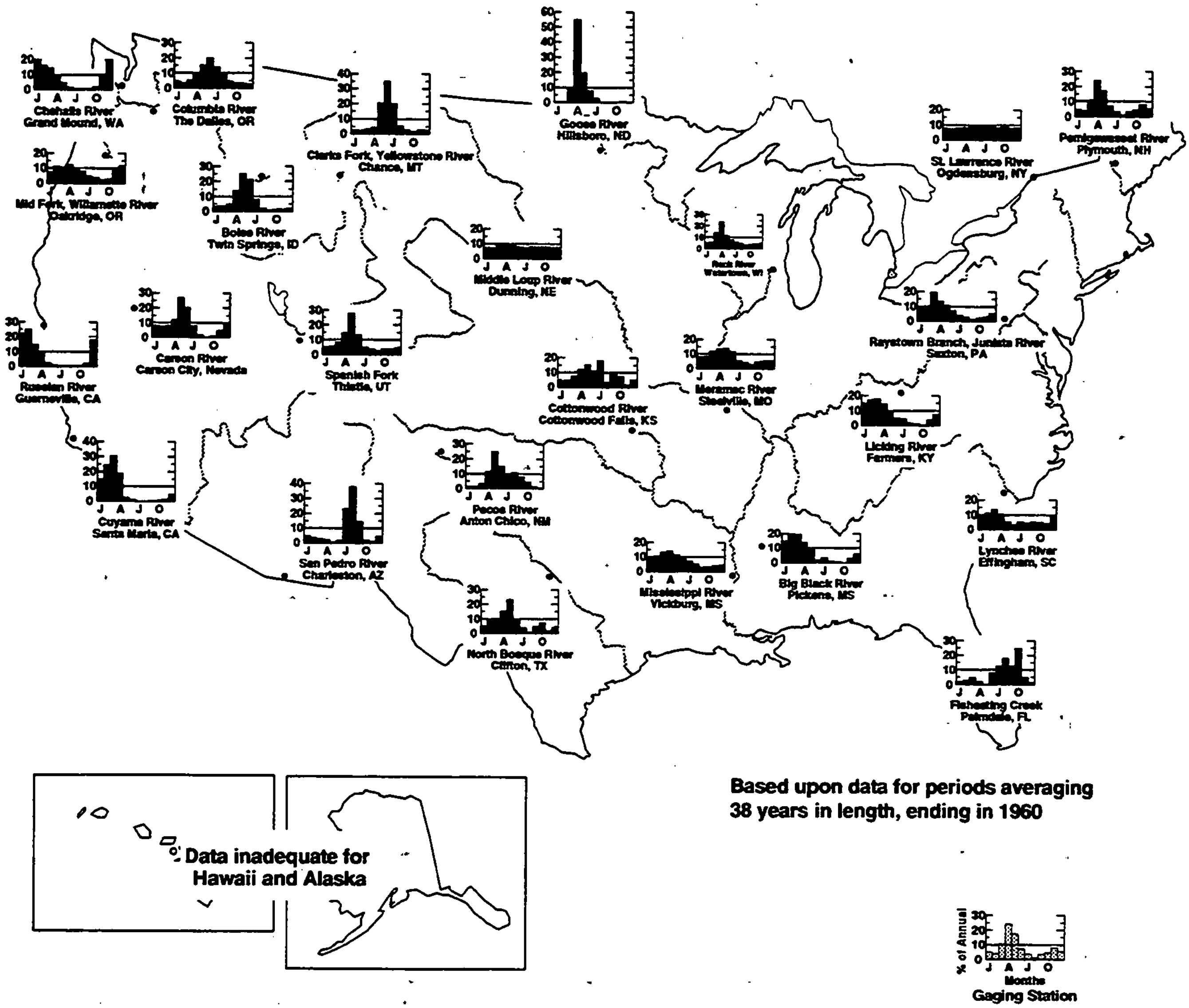


FIGURE E-11

Seasonal Distribution of Monthly Runoff in the United States
(after United States Geological Survey 1970)

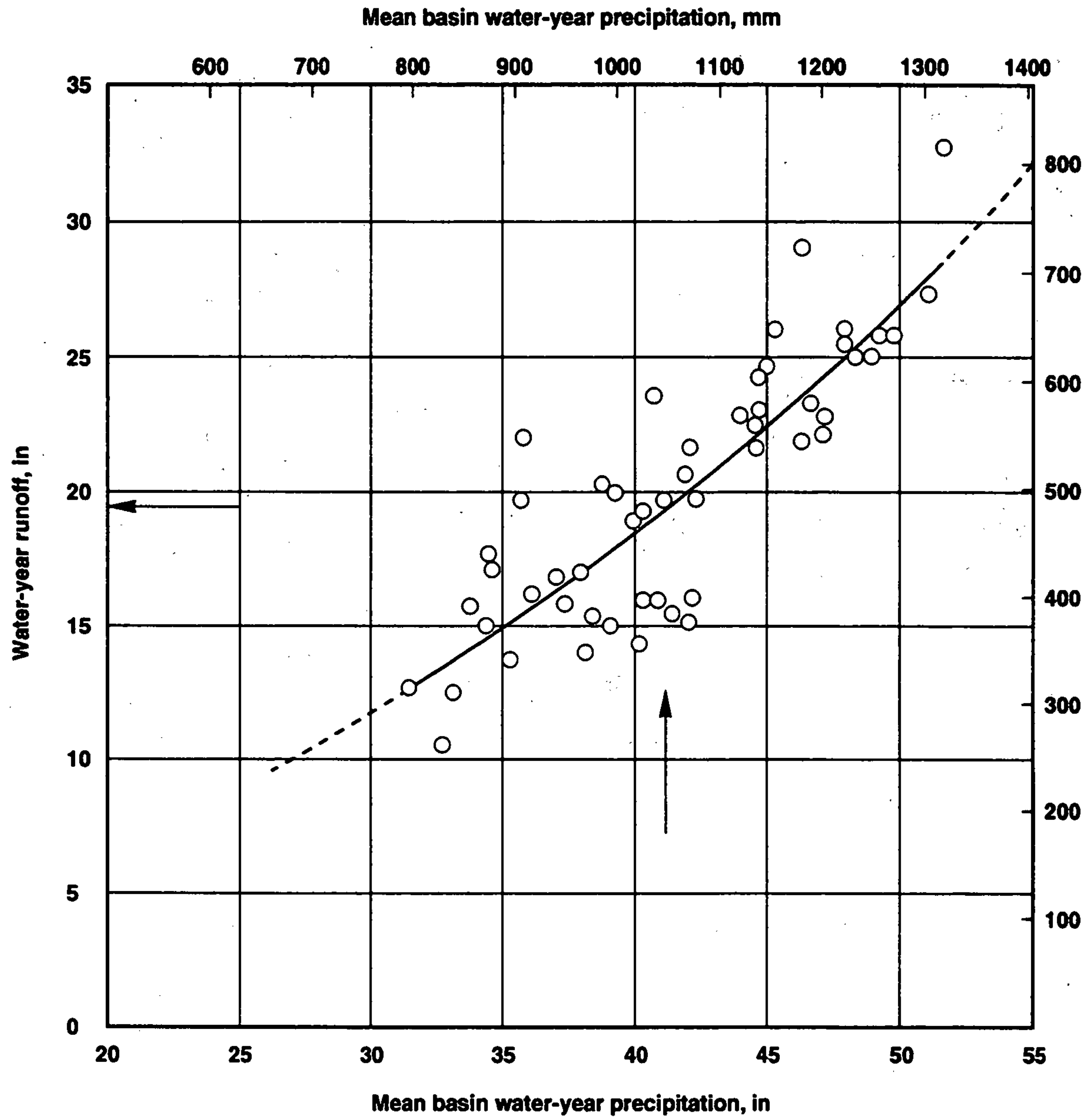


FIGURE E-12

Relationship Between Annual Precipitation and Runoff for the Merrimack River above Lawrence, MA (after Linsley at al. 1982)

04177000 OTTAWA RIVER AT TOLEDO UNIVERSITY, TOLEDO, OH

LOCATION.--Lat 41°39'36", long 83°36'44", in NE 1/4 sec. 32, T.9 S., R.7 E., Lucas County, Hydrologic Unit 04100001, on left bank at auto bridge at Toledo University, Toledo, Ohio., 0.4 mi downstream from Deline Ditch, 5.6 mi upstream from Sibley Creek, and 10.9 mi upstream from mouth.

DRAINAGE AREA.--150 mi². Area at site used prior to Sept. 30, 1948, 150 mi², revised.

PERIOD OF RECORD.--March 1945 to September 1948 (published as "Tenmile Creek at Toledo"), August 1976 to current year.

REVISED RECORDS.--WSP 1307: Drainage area.

GAGE.--Water-stage recorder. Datum of gage is 576.28 ft above National Geodetic Vertical Datum of 1929. (From Aug. 1976 to July, 1979 at site 500 ft downstream. Prior to Sept. 30, 1948 water-stage recorder at site 2,500 ft upstream at datum 3.72 ft higher.

REMARKS.--Estimated daily discharges: Dec. 13-22, Jan. 3-6, 11-18, 23-25, Feb. 5-14, 18-19, Feb. 26-Mar. 4. Records fair except estimated daily discharges which are poor. Water-quality data collected at this site 1977.

AVERAGE DISCHARGE.--16 years (1946-48, 1977-89) 127 ft³/s, 11.50 in/yr.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 3,950 ft³/s Mar. 14, 1982, gage height, 14.54 ft; minimum, no flow Aug. 24 to Sept. 19, 1945, July 7-15, Aug. 12-15, Sept. 1-9, 16-22, Oct. 5-10, 1946.

EXTREMES OUTSIDE PERIOD OF RECORD.--Flood of June 1, 1943 reached a stage of 15.1 ft present datum, from floodmark, Lucas County Sanitary Engineers, discharge, 3,400 ft³/s. Flood of Apr. 25, 1950 reached a stage of 15.0 ft present datum, from floodmark, discharge, 3,300 ft³/s.

EXTREMES FOR CURRENT YEAR.--Peak discharges greater than base discharge of 1150 ft³/s and maximum (*):

Date	Time	Discharge (ft³/s)	Gage height (ft)	Date	Time	Discharge (ft³/s)	Gage height (ft)
June 4	0300	*1,780	*10.95	June 20	0030	1,400	9.84

Minimum daily discharge, 7.6 ft³/s Oct. 1.

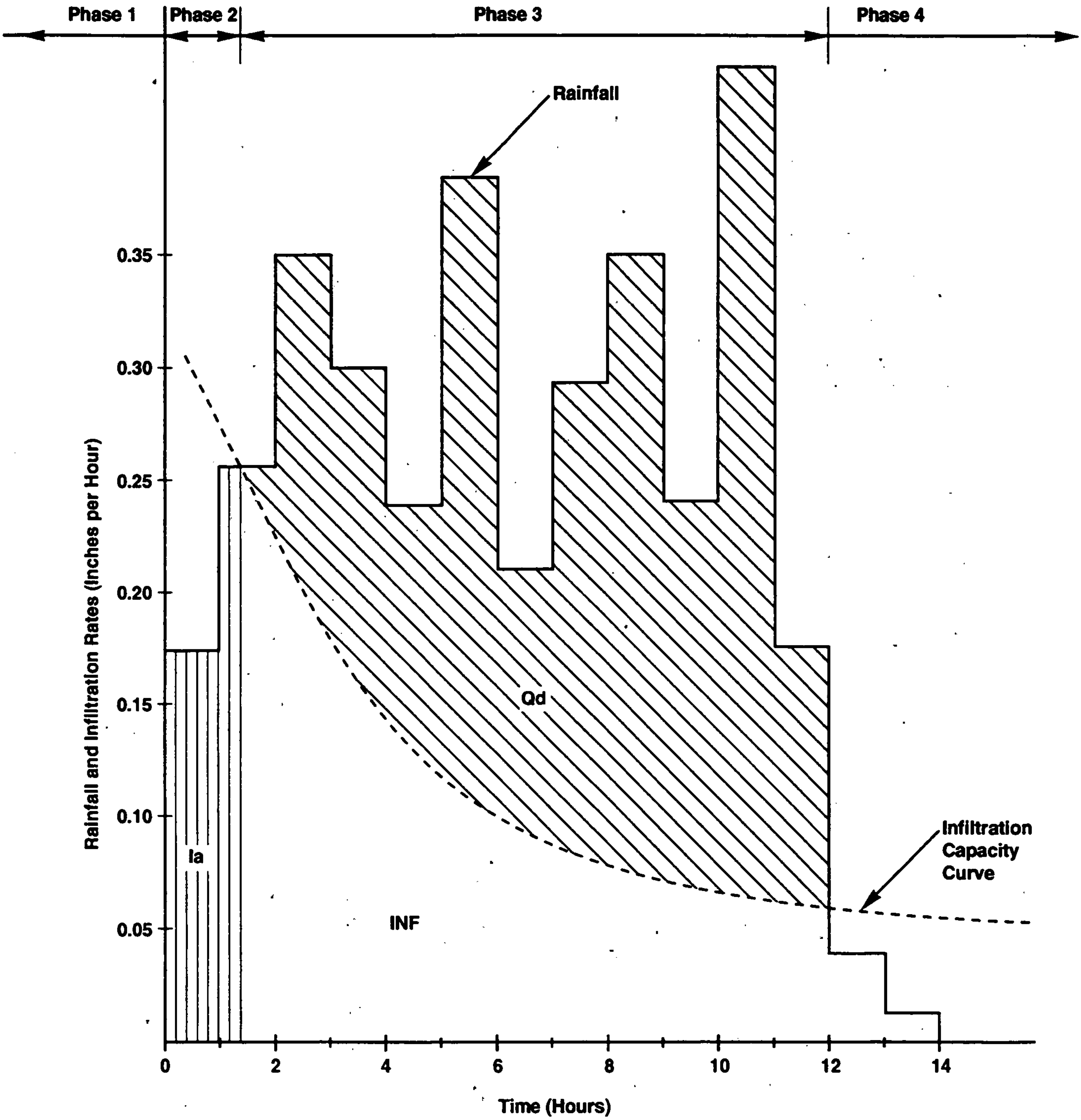
DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1988 TO SEPTEMBER 1989
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	7.6	25	54	86	160	18	56	44	1310	32	58	89
2	12	25	47	63	102	17	52	40	1380	188	49	38
3	20	24	41	48	71	16	314	39	1170	691	42	30
4	13	51	39	41	52	16	788	39	1720	215	36	25
5	11	196	37	37	39	32	532	45	1600	103	41	23
6	15	457	34	46	31	48	286	52	701	68	34	24
7	17	446	35	69	25	33	189	61	309	54	29	57
8	18	288	33	371	21	23	153	41	190	45	26	32
9	22	198	30	347	18	20	204	38	129	40	24	49
10	20	283	28	162	16	20	189	37	94	34	22	59
11	34	578	26	86	15	21	126	33	66	29	20	41
12	35	300	24	68	16	22	115	34	71	25	19	30
13	34	261	23	54	17	25	109	60	83	23	18	24
14	35	358	22	47	21	25	91	49	83	21	17	46
15	38	195	21	44	35	30	125	57	127	19	17	37
16	50	132	20	42	36	35	124	51	118	17	18	73
17	80	98	19	41	33	34	129	40	75	17	15	82
18	448	72	19	44	25	108	215	37	64	16	14	65
19	299	58	19	46	21	181	297	35	384	19	13	42
20	119	141	18	50	28	117	209	50	1260	570	45	31
21	64	495	19	46	42	96	136	36	770	365	57	26
22	49	443	21	43	41	79	98	34	537	305	24	22
23	54	194	66	39	40	74	77	33	253	158	20	19
24	51	121	102	37	32	72	65	30	142	82	19	16
25	56	88	126	36	25	69	92	76	164	90	16	15
26	57	74	101	110	22	62	83	135	108	574	14	14
27	43	83	96	323	20	97	72	185	67	250	14	13
28	35	78	439	168	19	128	62	89	54	350	23	13
29	29	68	525	171	---	82	56	58	42	180	24	13
30	29	57	192	397	---	71	51	63	37	100	18	11
31	27	---	146	268	---	65	---	742	---	73	14	---
TOTAL	1821.6	5887	2422	3430	1023	1736	5095	2363	13108	4753	800	1059
MEAN	58.8	196	78.1	111	36.5	56.0	170	76.2	437	153	25.8	35.3
MAX	448	578	525	397	160	181	788	742	1720	691	58	89
MIN	7.6	24	18	36	15	16	51	30	37	16	13	11
CFSM	.39	1.31	.52	.74	.24	.37	1.13	.51	2.91	1.02	.17	.24
IN.	.45	1.46	.60	.85	.25	.43	1.26	.59	3.25	1.18	.20	.26

CAL YR 1988 TOTAL 28144.9 MEAN 76.9 MAX 861 MIN 1.9 CFSM .51 IN. 6.98
WTR YR 1989 TOTAL 43497.6 MEAN 119 MAX 1720 MIN 7.6 CFSM .79 IN. 10.79

FIGURE E-13

USGS Annual Water Resources Data—Typical Surface Water Data Station Format (United States Geological Survey 1970)



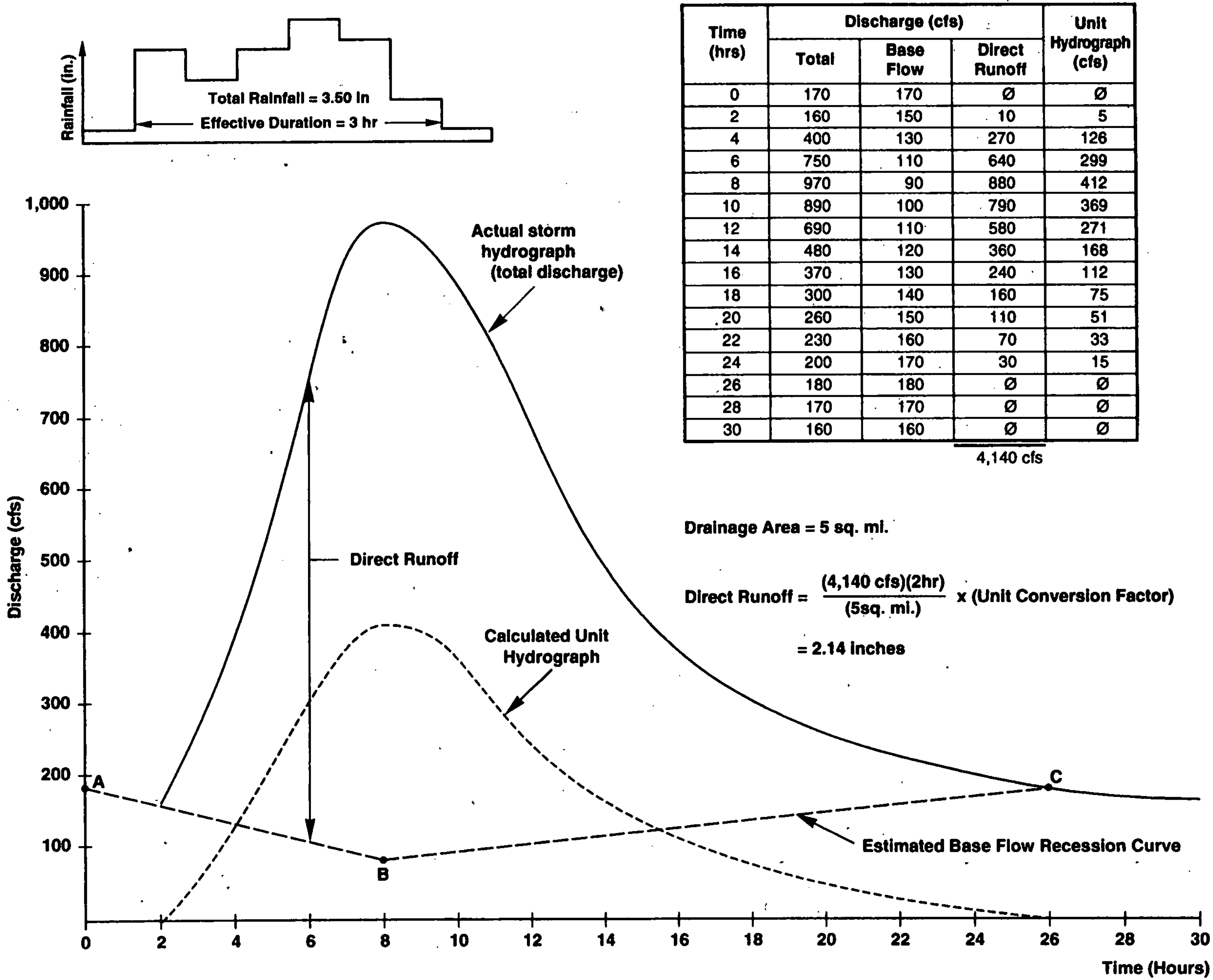
Legend: Ia = Initial Abstraction (in.)

Qd = Direct Runoff (in.)

INF = Infiltration (in.)

FIGURE E-14

Direct Runoff Process



Time (hrs)	Discharge (cfs)			Unit Hydrograph (cfs)
	Total	Base Flow	Direct Runoff	
0	170	170	Ø	Ø
2	160	150	10	5
4	400	130	270	126
6	750	110	640	299
8	970	90	880	412
10	890	100	790	369
12	690	110	580	271
14	480	120	360	168
16	370	130	240	112
18	300	140	160	75
20	260	150	110	51
22	230	160	70	33
24	200	170	30	15
26	180	180	Ø	Ø
28	170	170	Ø	Ø
30	160	160	Ø	Ø
			4,140 cfs	

Drainage Area = 5 sq. mi.

$$\text{Direct Runoff} = \frac{(4{,}140\ \text{cfs})(2\text{hr})}{(5\text{sq. mi.})} \times (\text{Unit Conversion Factor})$$

= 2.14 inches

FIGURE E-15

Unit Hydrograph Method

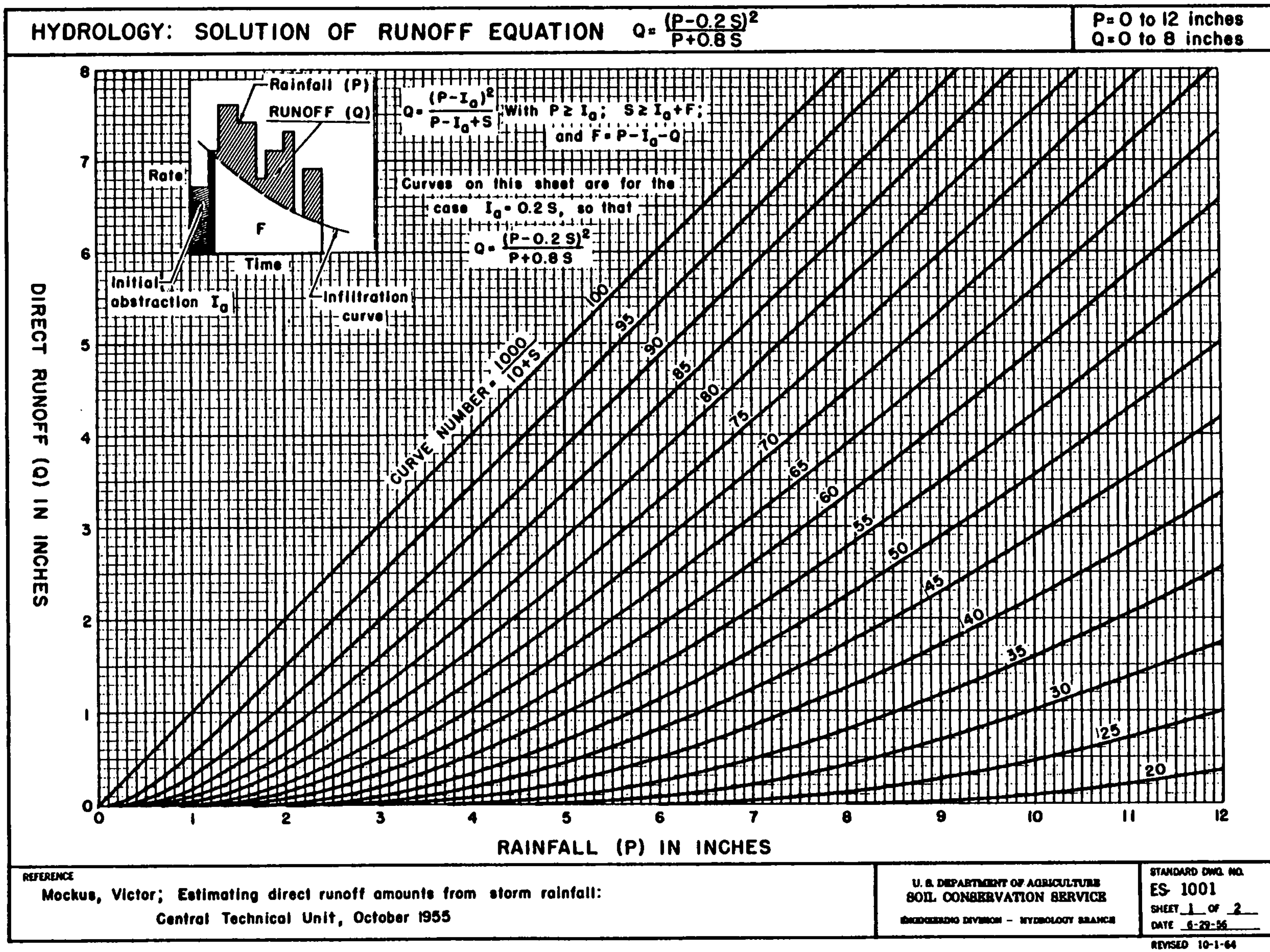


FIGURE E-16

SCS Graphical Relationship Between Rainfall and Direct Runoff (after U.S. Soil Conservation Service NEH–4 1985)

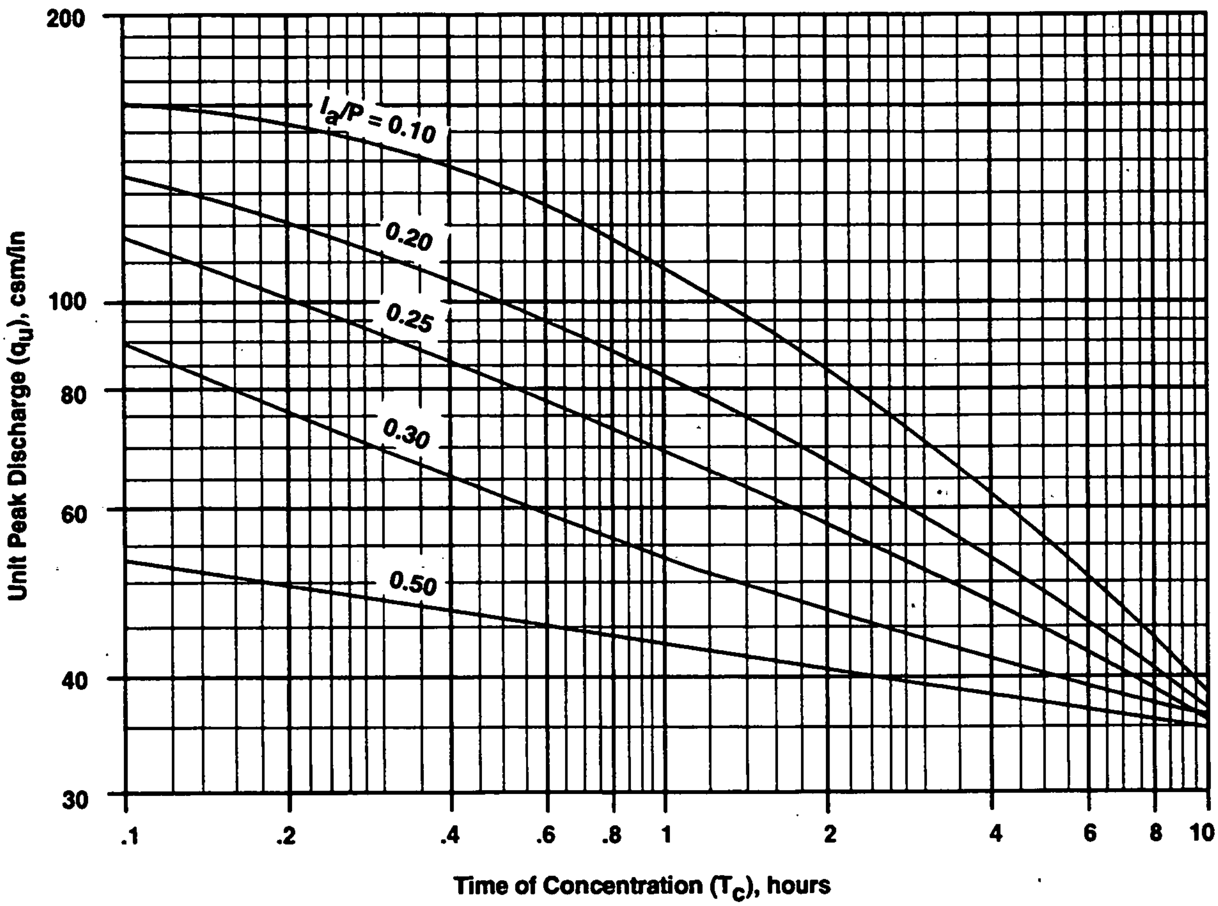


FIGURE E-17

SCS Graphical Determination of Peak Discharge (after U. S. Soil Conservation Service TR-55 1986)

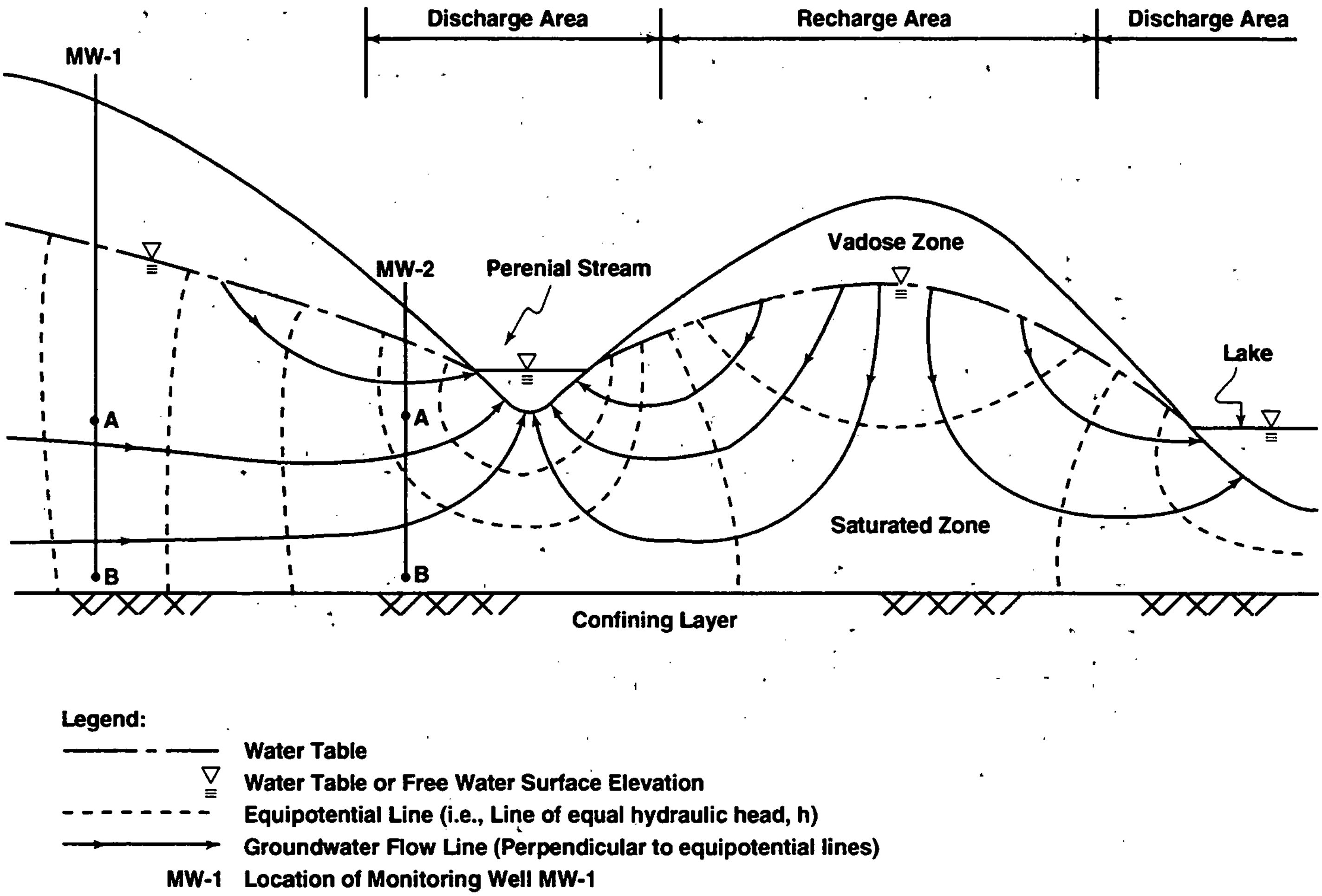


FIGURE E-18

Shallow Groundwater Flow System

392009082072200. Local number, AT-5

LOCATION.--Lat 39°20'09", long 82°07'22", Hydrologic Unit 05030204, in Athens well field along Hocking River.
Owner: Athens Water Department.

AQUIFER.--Sand and gravel of Quaternary Age.

WELL CHARACTERISTICS.--Drilled unused water table well, diameter 12 in., depth 48 ft, cased.

INSTRUMENTATION.--Digital recorder -- 60-minute punch.

DATUM.--Elevation of land surface datum is 640 ft above National Geodetic Vertical Datum on 1929, from topographic map. Measuring point: Floor of instrument shelter, 4.75 ft above land-surface datum.

REMARKS.--Station operated by Ohio Department of Natural Resources, Division of Water.

PERIOD OF RECORD.--July 1982 to current year.

EXTREMES FOR PERIOD OF RECORD.--Maximum daily low, 22.35 ft below land-surface datum, Oct. 19, 20, 1986; Minimum daily low 12.07 ft below land-surface datum, May 5, 1983.

DEPTH BELOW LAND SURFACE (WATER LEVEL) (FEET), WATER YEAR OCTOBER 1988 TO SEPTEMBER 1989
MAXIMUM VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	20.29	20.20	18.64	18.30	18.64	16.25	15.15	13.90	14.81	16.88	17.96	17.15
2	20.37	20.20	18.66	18.31	18.63	16.37	14.72	14.11	15.17	17.02	18.01	17.30
3	20.41	20.19	18.79	18.27	18.69	16.50	14.82	14.26	15.72	17.08	18.00	17.44
4	20.44	20.19	18.82	18.23	18.54	16.57	14.85	14.45	16.03	17.12	18.02	17.56
5	20.42	20.11	18.86	18.26	18.54	16.58	14.71	14.57	16.08	17.15	17.84	17.66
6	20.45	20.05	18.89	18.26	18.66	16.14	14.78	14.68	16.20	17.00	16.94	17.77
7	20.50	19.80	18.96	17.93	18.63	15.30	15.13	14.75	16.35	17.35	16.09	17.84
8	20.53	19.62	18.92	17.65	18.62	15.46	15.24	14.88	16.34	17.33	16.18	17.87
9	20.53	19.54	19.04	17.41	18.64	15.55	15.46	15.08	16.59	17.45	16.35	17.95
10	20.46	19.55	19.09	17.41	18.52	15.53	15.59	14.92	16.58	17.62	16.50	18.03
11	20.52	19.55	19.17	17.48	18.42	15.55	15.74	14.67	16.90	17.55	16.72	18.10
12	20.55	19.37	19.17	17.54	18.50	15.64	15.92	14.75	16.99	17.78	16.88	18.18
13	20.57	19.32	19.11	17.45	18.52	15.78	15.93	15.14	16.99	17.83	17.04	18.25
14	20.60	19.28	19.12	17.39	18.52	15.70	16.14	15.17	16.88	17.83	17.16	18.31
15	20.62	19.24	19.16	17.29	18.13	15.86	16.22	15.21	16.90	17.84	17.27	18.36
16	20.63	19.16	19.16	17.08	17.35	15.96	16.39	14.98	15.98	17.95	17.39	18.23
17	20.64	19.16	19.18	17.26	16.61	16.14	16.50	14.83	15.81	17.89	17.48	18.24
18	20.67	19.08	19.20	17.40	16.37	16.30	16.56	15.04	15.83	18.16	17.57	18.30
19	20.67	19.06	19.23	17.52	16.37	16.40	16.41	15.07	16.19	18.26	17.68	18.39
20	20.46	19.04	19.25	17.67	16.34	16.52	15.78	15.32	16.30	18.27	17.82	18.43
21	20.41	18.69	19.26	17.82	16.42	16.46	15.84	15.43	16.51	18.24	17.88	18.48
22	20.42	18.36	19.26	17.97	15.84	16.00	15.83	15.71	16.52	18.23	17.89	18.50
23	20.35	18.25	19.21	18.12	15.48	15.94	16.01	15.82	16.31	18.26	17.82	18.44
24	20.35	18.30	19.18	18.23	15.58	16.11	16.08	15.58	16.71	18.43	17.43	17.88
25	20.35	18.41	18.83	18.29	15.73	16.16	16.36	14.99	16.72	18.51	17.16	17.74
26	20.38	18.45	18.48	18.41	15.88	16.18	16.21	14.78	16.96	18.62	17.08	17.80
27	20.38	18.48	18.47	18.41	15.93	16.37	15.51	14.11	16.97	18.64	17.16	17.93
28	20.42	18.55	18.54	18.45	16.05	16.50	15.27	13.27	17.08	18.31	17.26	18.00
29	20.41	18.64	18.51	18.49	---	16.57	15.09	13.53	16.79	18.13	17.41	18.19
30	20.36	18.65	18.27	18.54	---	16.40	14.46	13.98	16.51	18.15	17.41	18.19
31	20.33	---	18.25	18.57	---	15.75	---	14.38	---	18.16	17.05	---
MAX	20.67	20.20	19.26	18.57	18.69	16.58	16.56	15.82	17.08	18.64	18.02	18.50

CAL YR 1988 LOW 20.74
WTR YR 1989 LOW 20.67

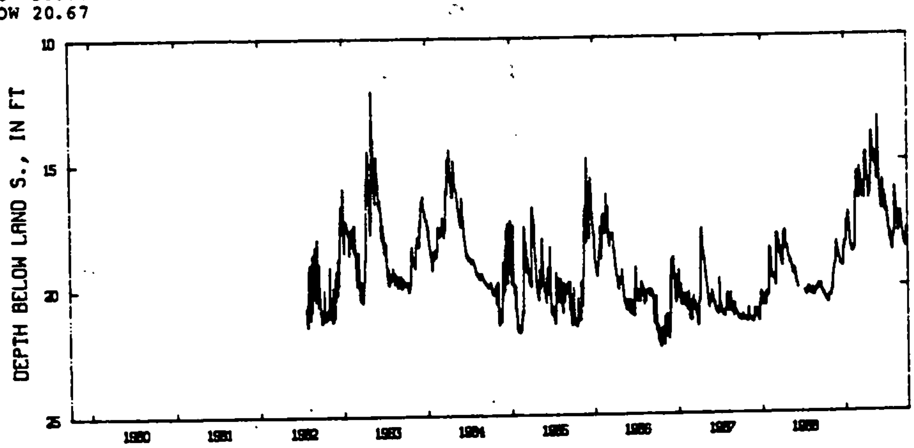


FIGURE E-19

Water Table Fluctuations
(after U.S. Geological Survey 1990)

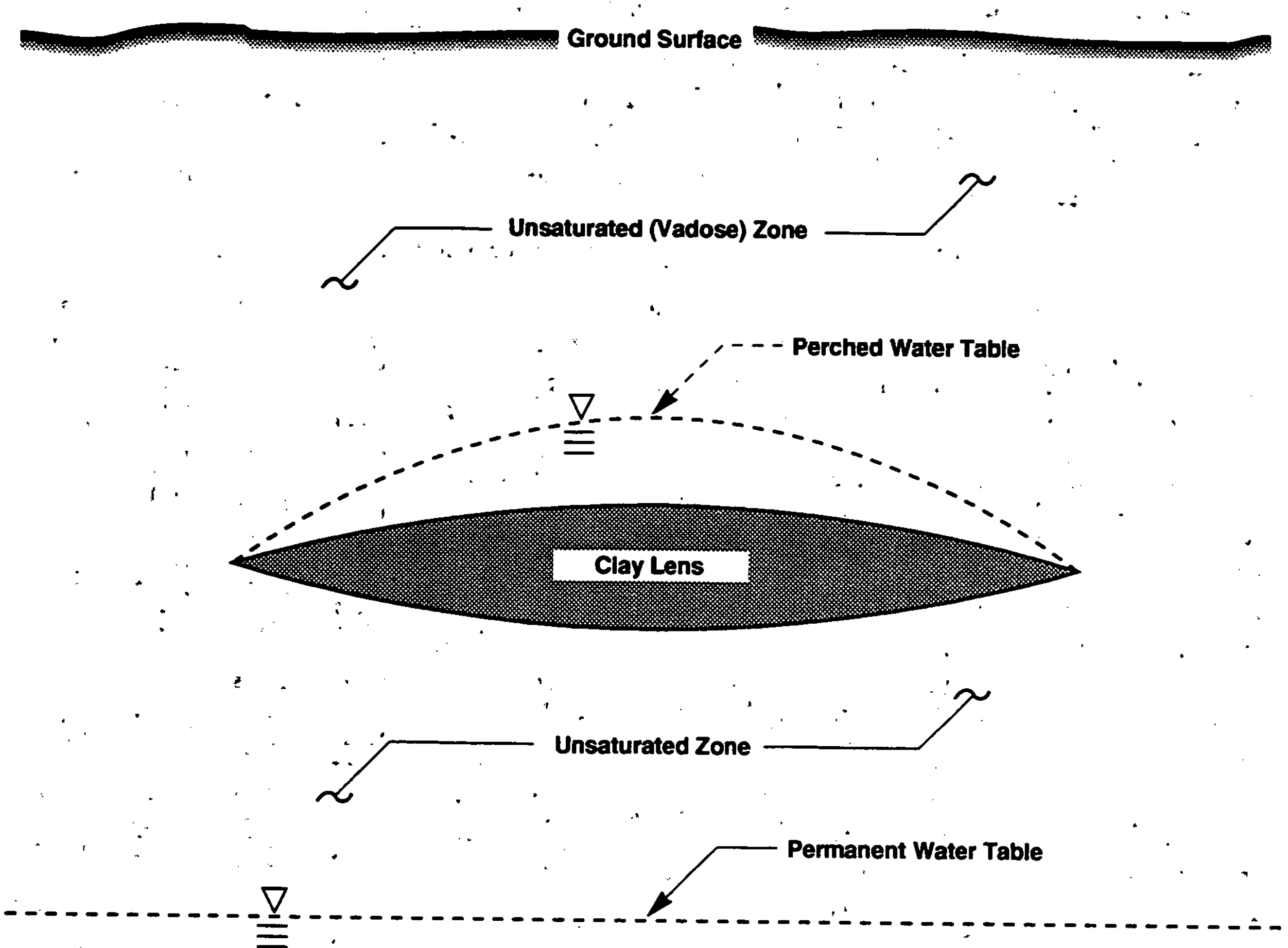


FIGURE E-20

Perched Water Table

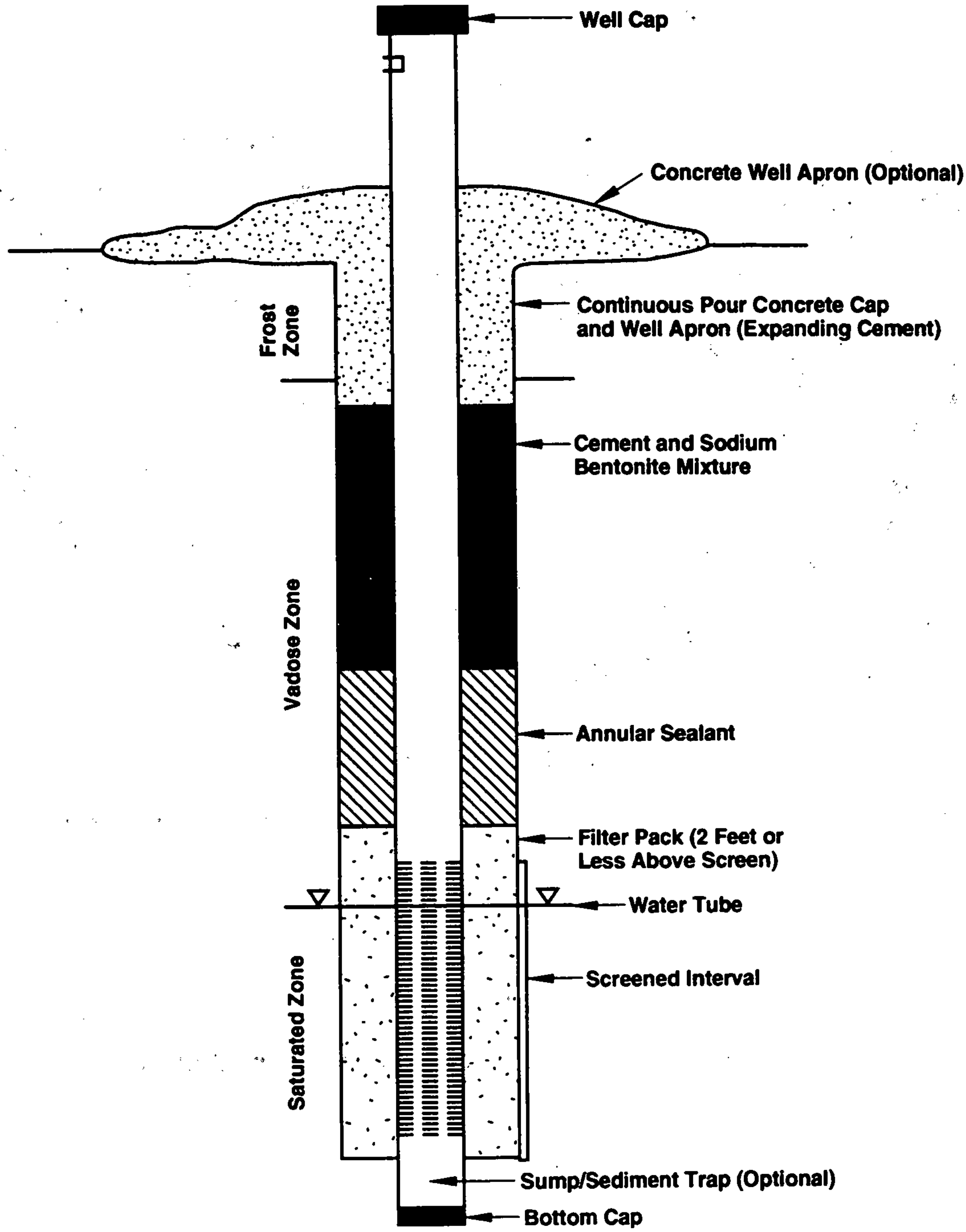


FIGURE E-21

Typical Groundwater Monitoring Well Construction Detail

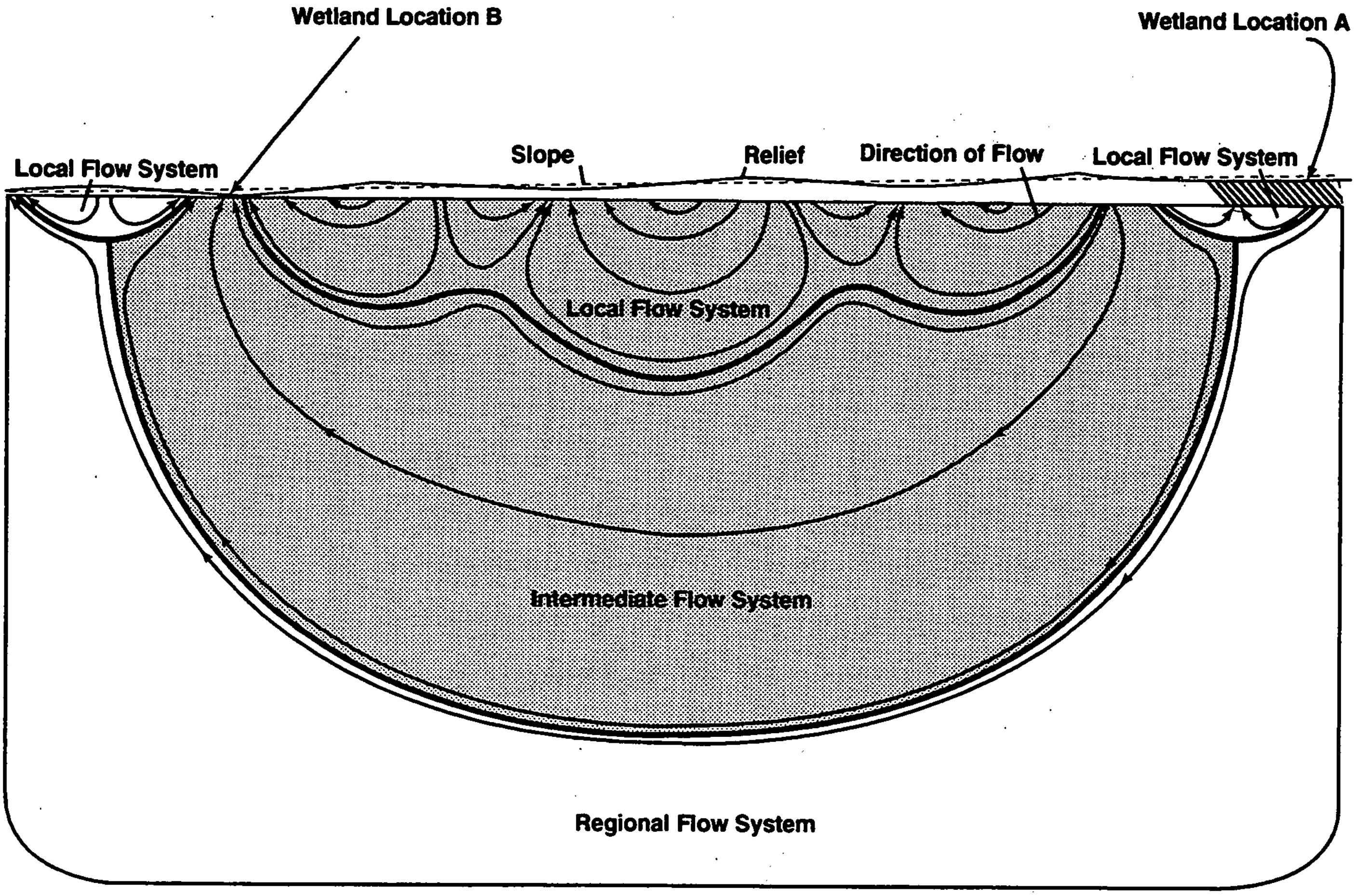


FIGURE E-22

Local, Intermediate, and Regional Groundwater Flow Systems (after Toth 1963)

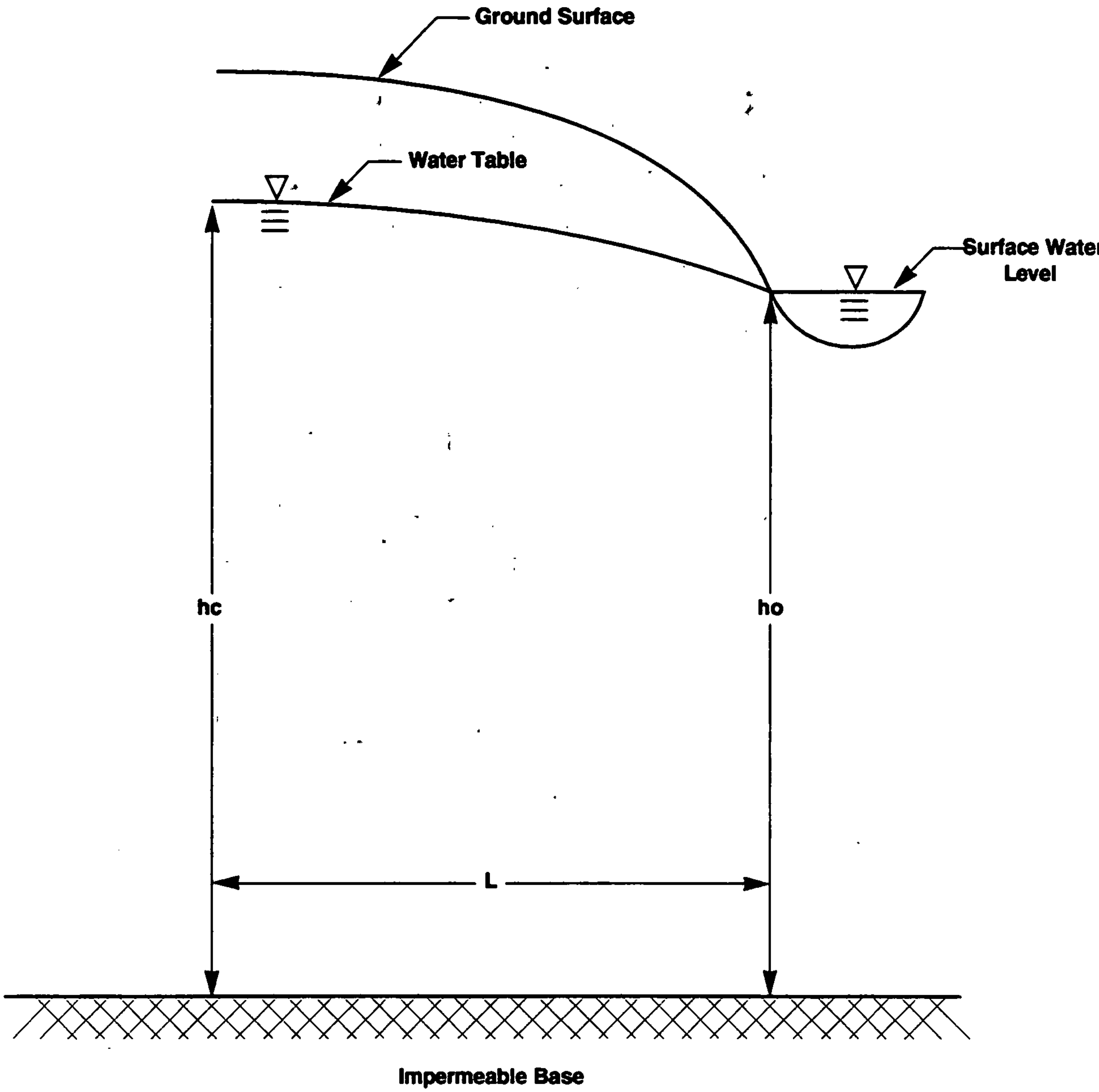


FIGURE E-23

Dupuit-Forchheimer Assumptions—Two Dimensions

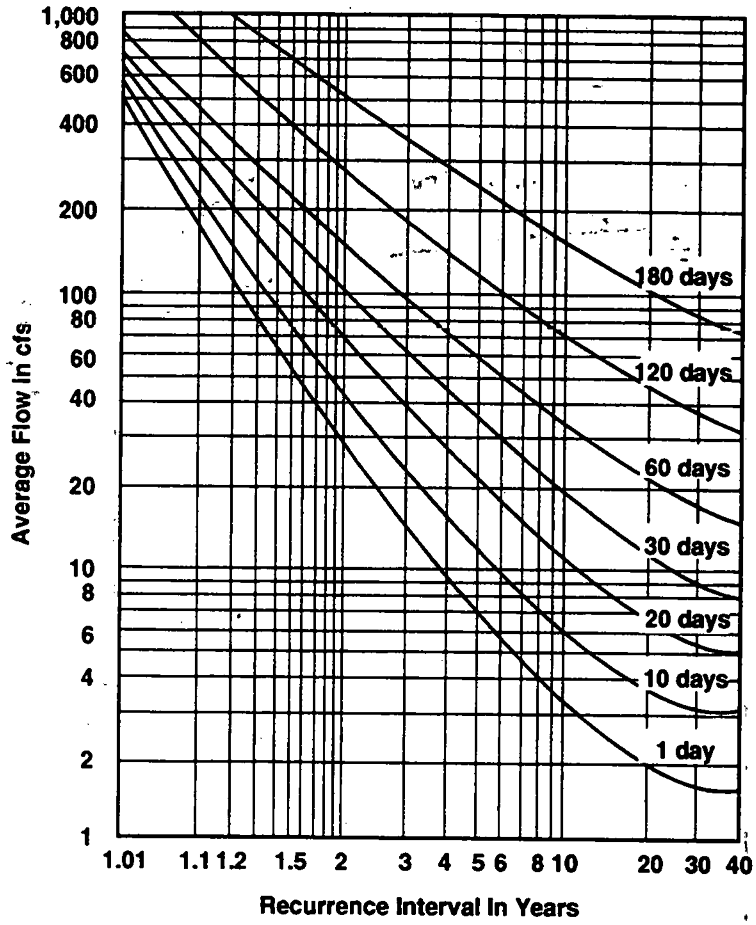
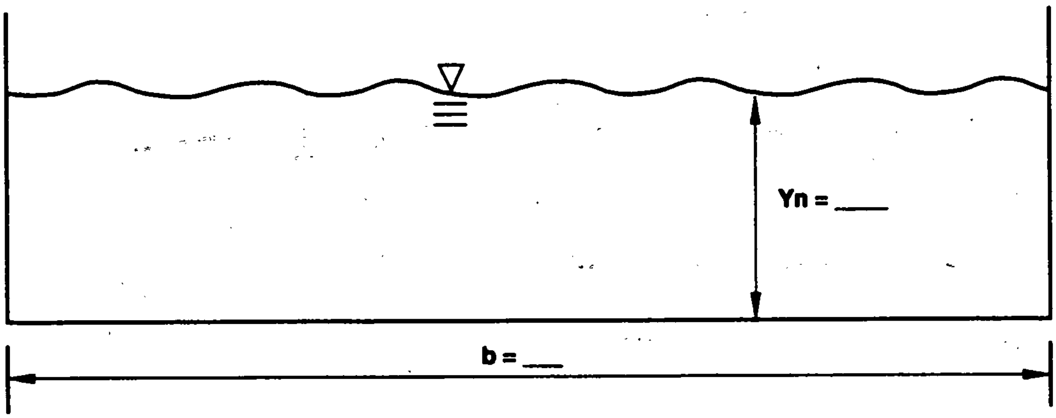


FIGURE E-24

Typical Discharge–Duration–Frequency Curve for Low Streamflow Conditions

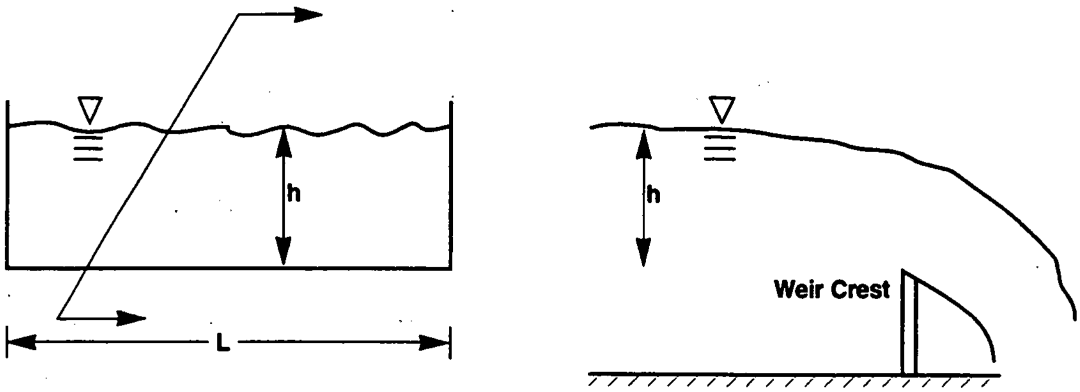


Notes:
S = channel bottom slope (ft/ft)
n = Manning's roughness coefficient (dimensionless)

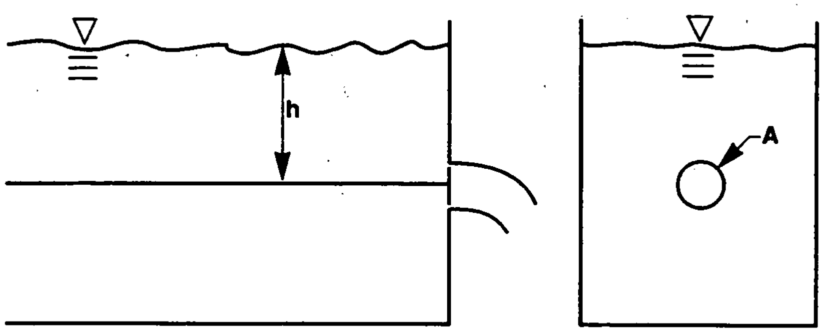
S (surveyed) = ______________
$A = bYn =$ ______________ ft.²
$WP = b + 2Yn =$ ______________ ft.
$R = A/WP =$ ______________ ft.
n = __________ (describe channel)
$q = \frac{1.49}{n} AR^{2/3} S^{1/2} =$ ________ cfs

FIGURE E-25

Application of the Manning Formula for a Rectangular Channel



Weir Flow (Sharp-Crested Weir)



Orifice Flow

FIGURE E-26

Weir and Orifice Flow Calculations

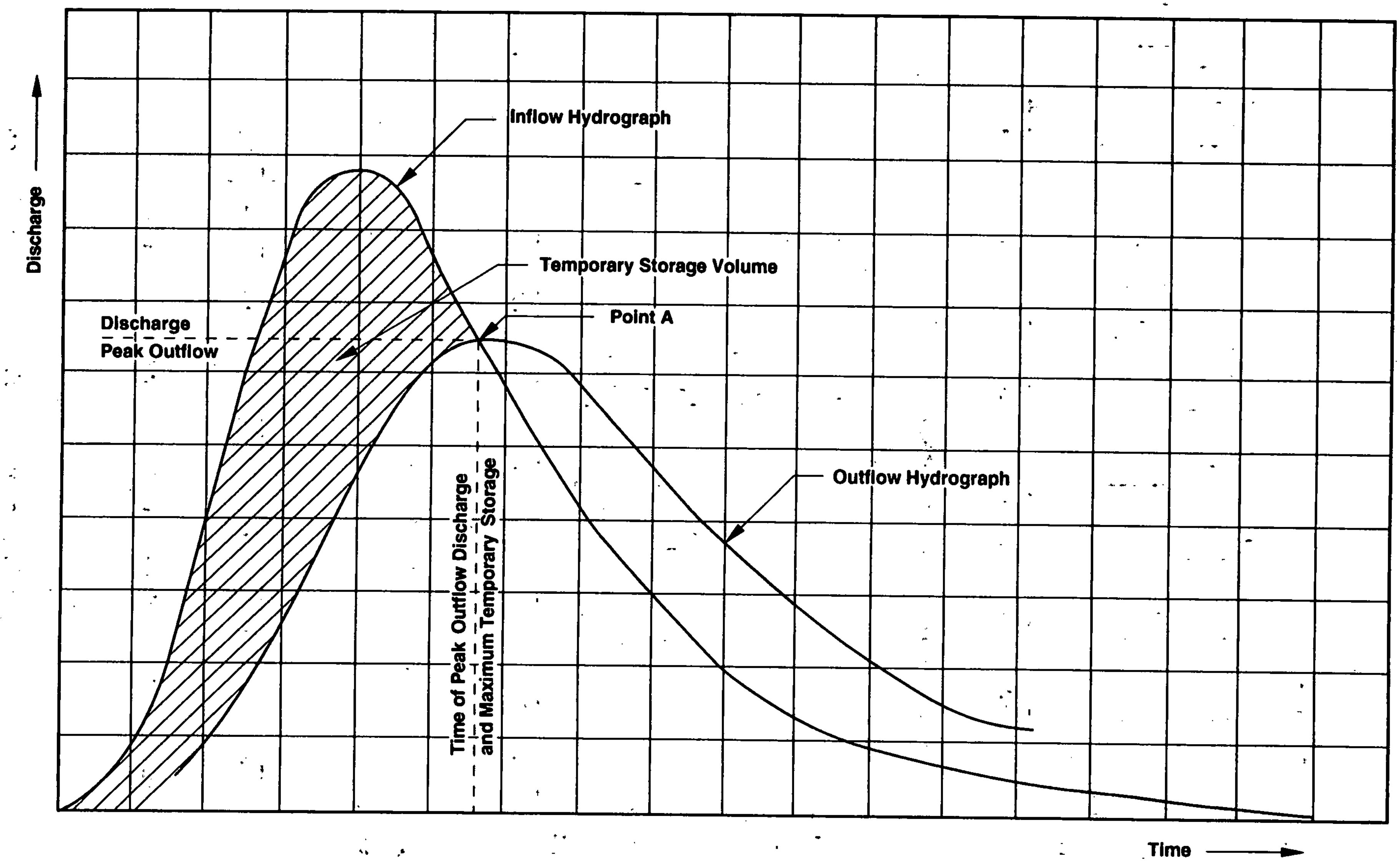
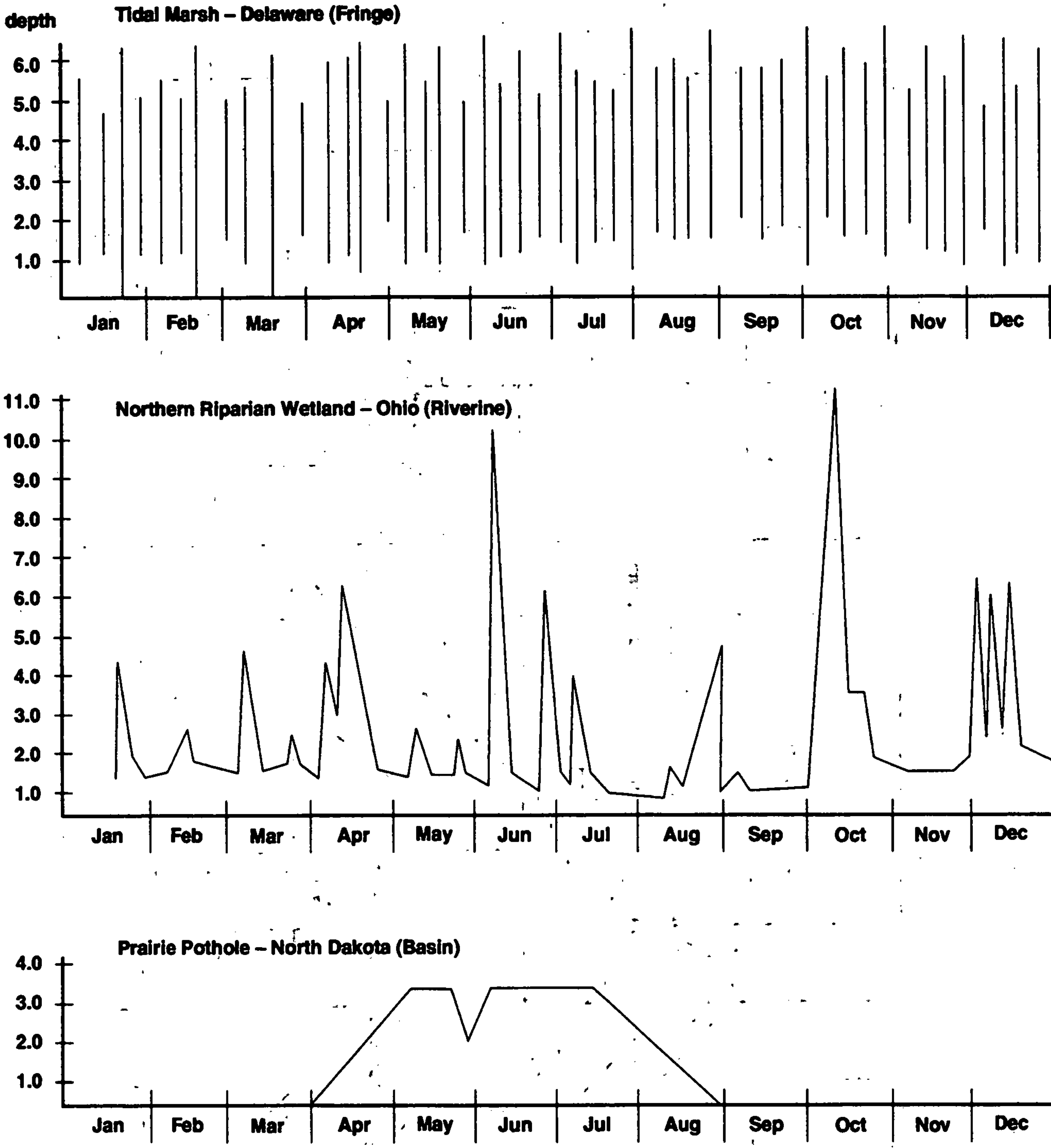


FIGURE E-27
Basic Flood Routing Relationship



Note: Vertical Axis (depth) denotes water depth relative to wetland bottom

FIGURE E-28

Typical Hydroperiods for Different Types of Wetlands

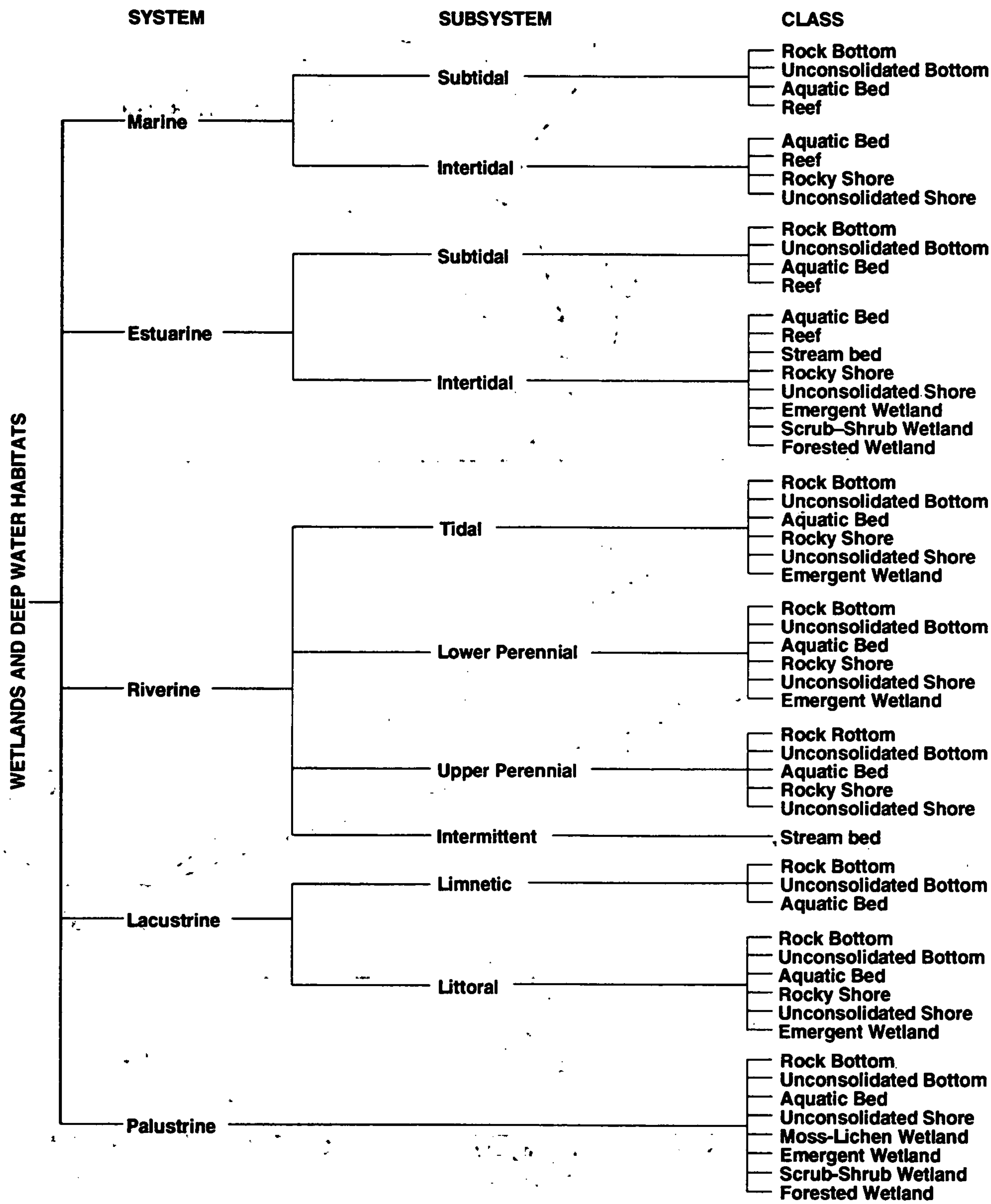


FIGURE E-29

USFWS Wetland Classification System
(after Cowardin et al. 1979)

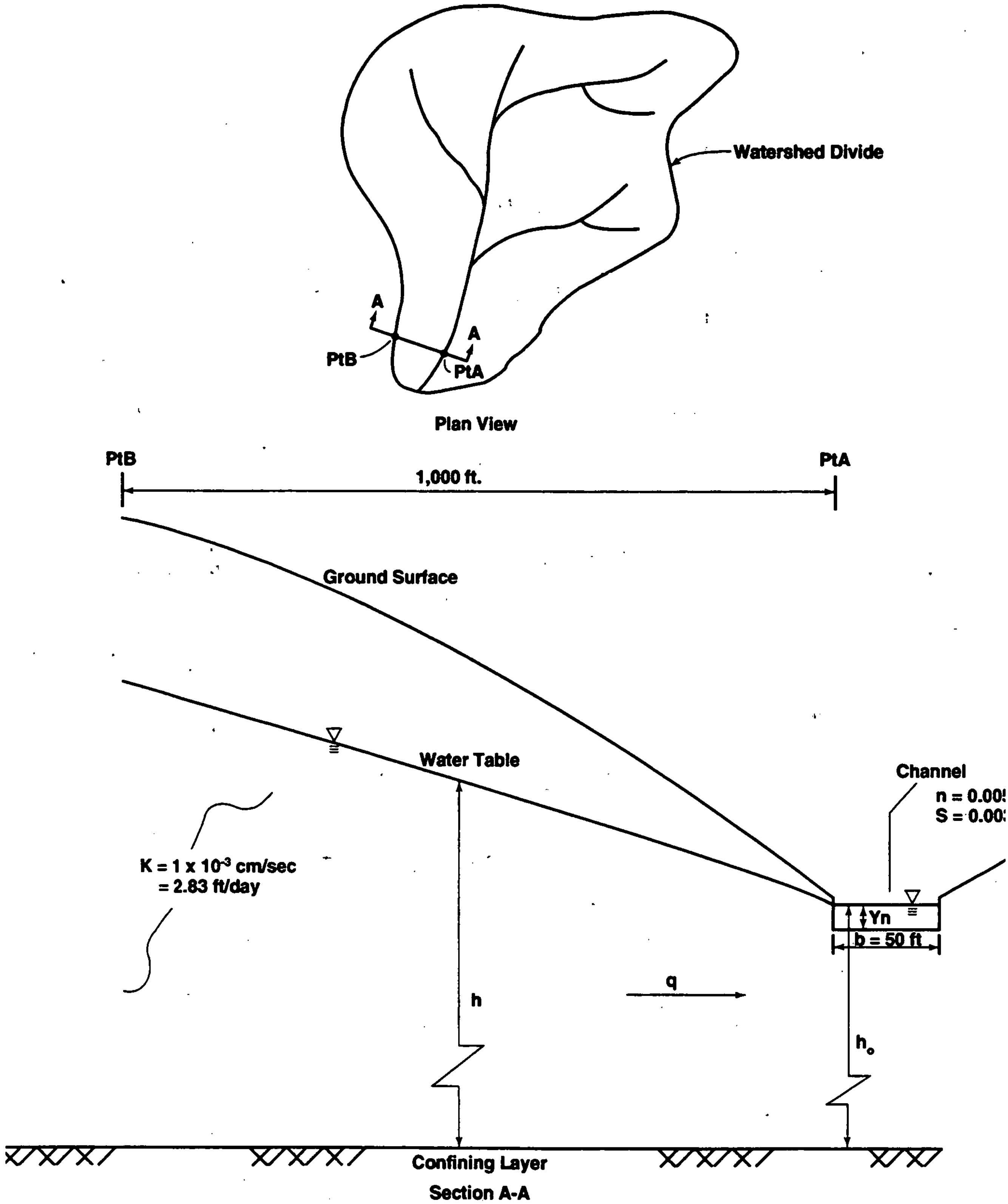
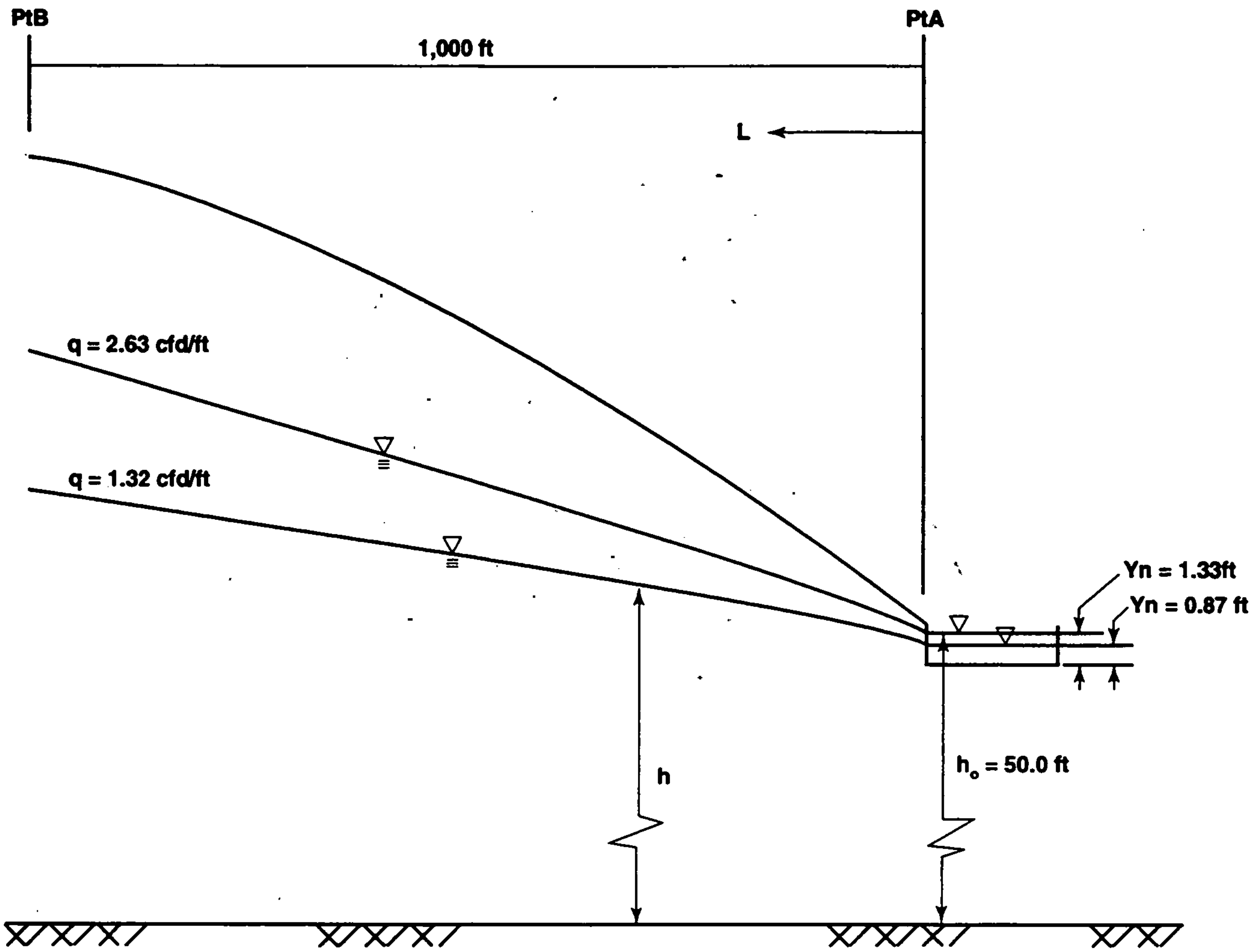


FIGURE E-30

Surface Water Versus Groundwater Elevation Fluctuations
Example Problem Statement



L (ft)	h (ft)	
	q = 2.63 cfd/ft	q = 1.32 cfd/ft
0	50.0	49.5
100	51.8	50.5
200	53.6	51.4
300	55.3	52.3
500	58.6	54.0
700	61.7	55.7
1,000	66.0	58.2

Notes:

▽ = Water table or surface water elevation

cfd = Cubic feet per day

FIGURE E-31

Surface Water Versus Groundwater Elevation Fluctuations Example Problem Results

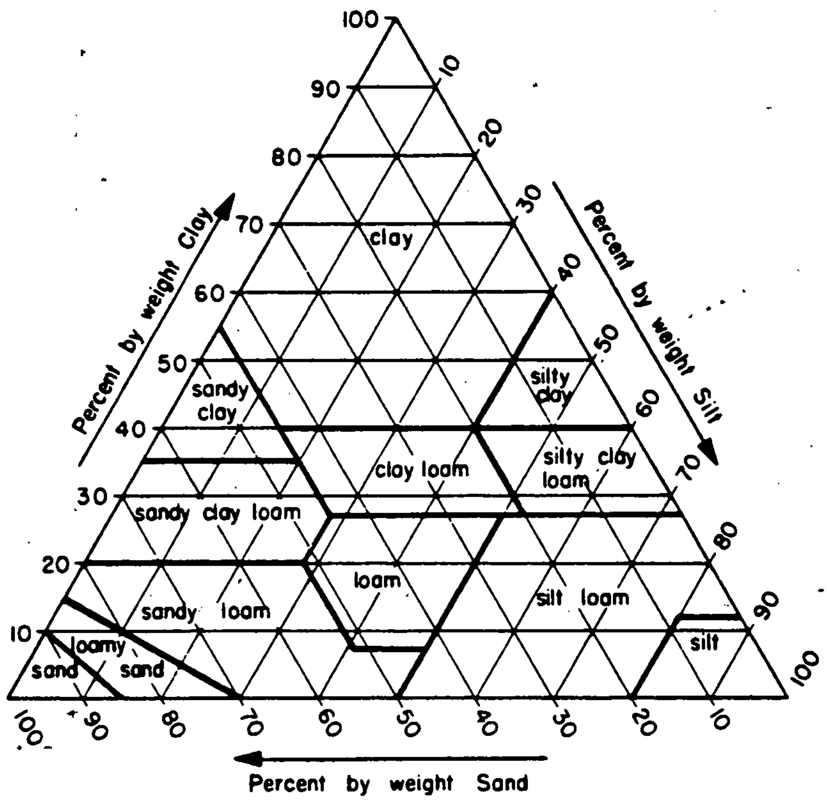
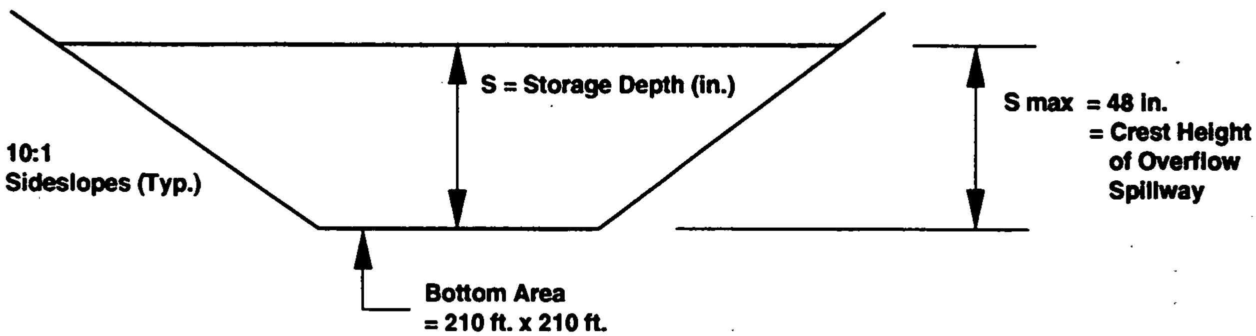


FIGURE E-32

Soil Conservation Service Soil Texture Classes

Watershed Area Tributary to Wetland
Locations: (a) Columbus, OH (Lat = 40° N)
(b) Bismark, ND (Lat = 47° N)
Watershed Area: 200 acres
Average Hydrologic Soil Group: C
Cover Type: Farmsteads (50%)/Residential – 1/2 acre lots (50%)
Weighted Curve Number (Table F-2b): (0.5) (82) + (0.5) (80) = 81

Proposed Wetland Configuration
Note: Wetland bottom soil = Silty clay loam



S (in.)	Top Dimensions (ft. x ft.)	Area (ft.^{2} x 10^3)	Area (ac)	Avg. Area (ft.^{2} x 10^3)	ΔS (ft.)	ΔStorage (ft.^{3} x 10^3)	Storage (ft.^{3} x 10^3)
0	210 x210	44.1	1.01				0
				48.5	1.0	48.5	
12	230 x 230	52.9	1.21				48.5
				57.7	1.0	57.7	
24	250 x 250	62.5	1.43				106.
				67.7	1.0	67.7	
36	270 x 270	72.9	1.67				174.
				78.5	1.0	78.5	
48	290 x 290	84.1	1.93				252.

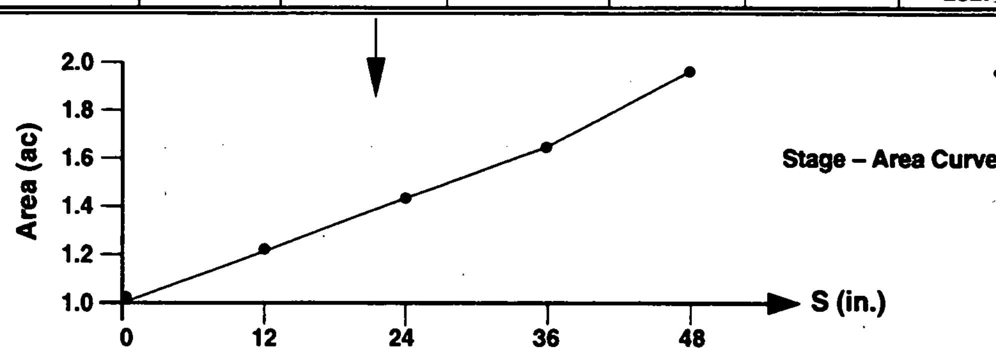


FIGURE E-33

Water Balance Example—Problem Statement

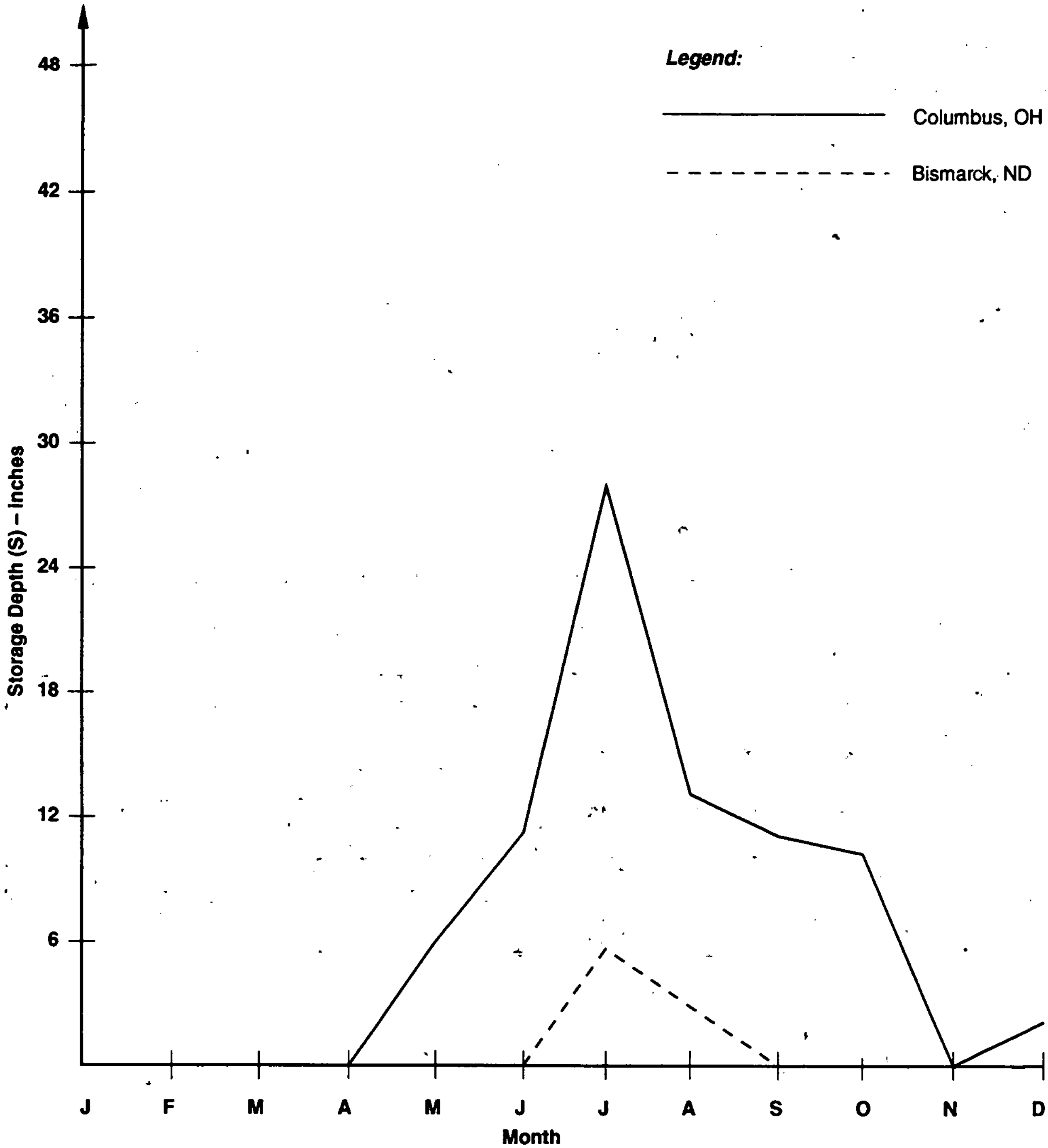
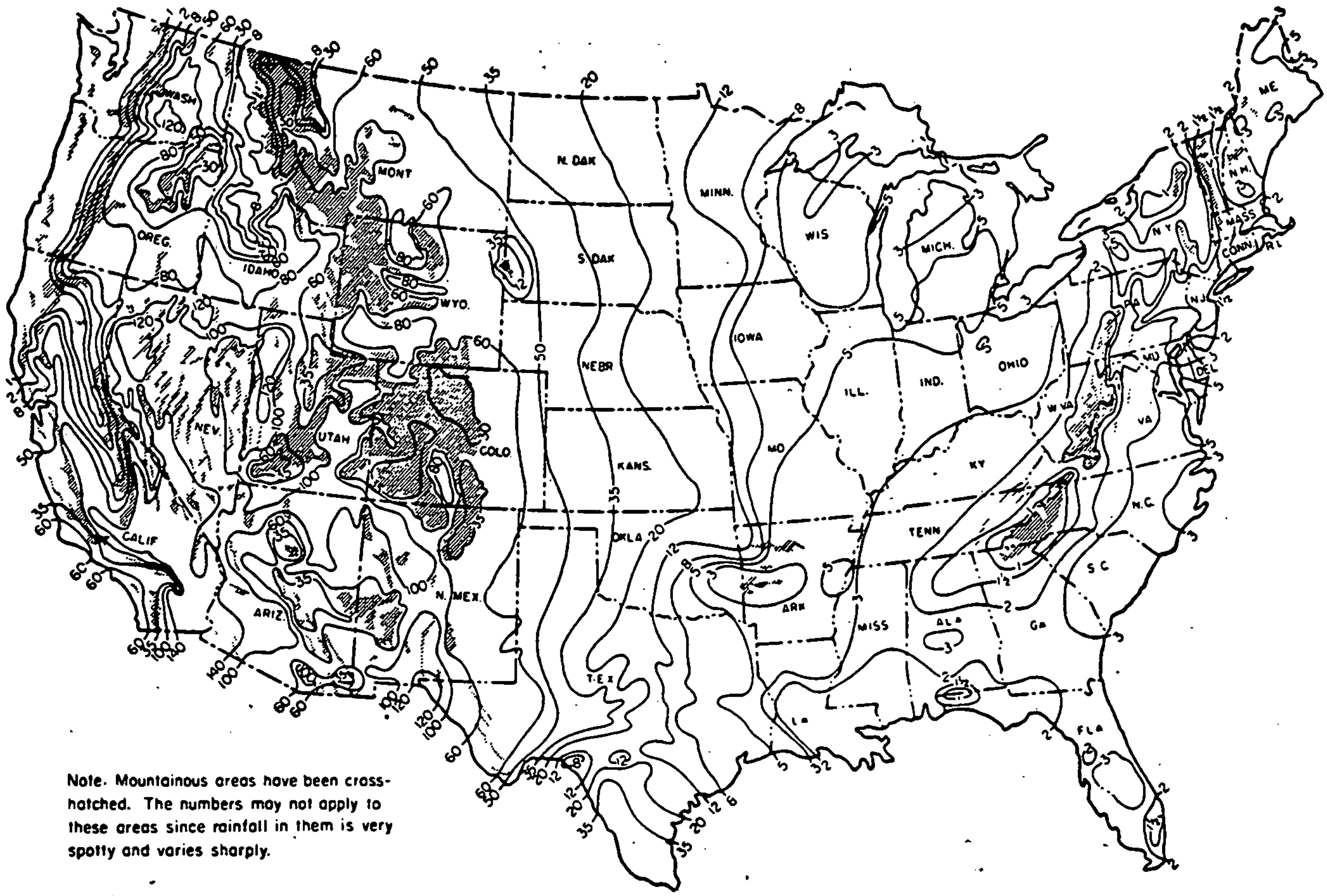


FIGURE E-34

Water Balance Example—Hydroperiod Results



5 = number of acres

FIGURE E-35

Guide to Estimating Drainage Area for Farm Ponds (after U.S. Soil Conservation Service 1976)

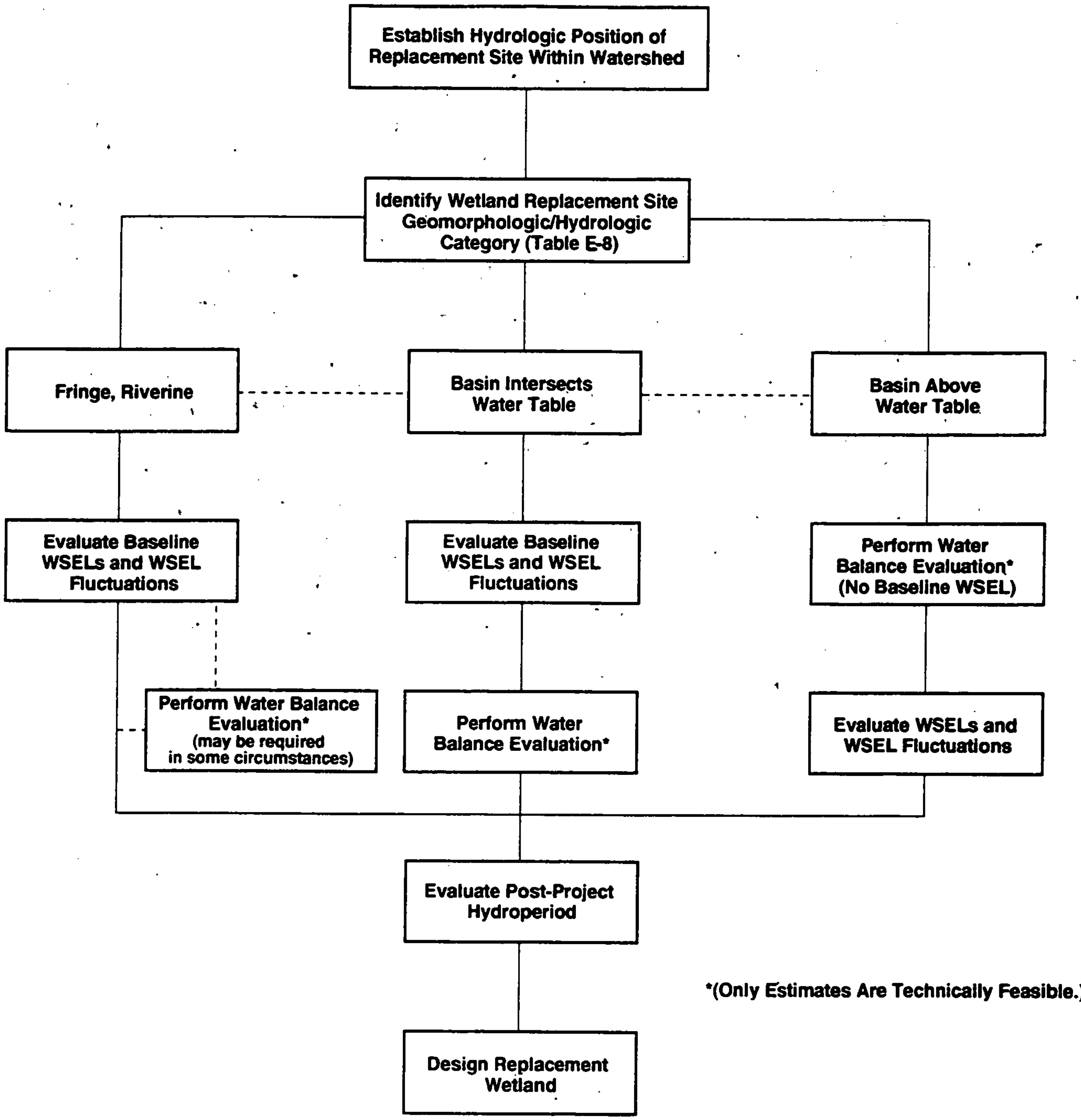


FIGURE E-36

Framework for Hydrologic Design of Replacement Wetlands

APPENDIX F
SOILS

In addition to the references cited at the end of this appendix, authors contacted the individuals listed below about their expertise on various wetland replacement topics. These contacts are noted in the text parenthetically as "(NAME personal communication)." The Research Team recommends that users of the manual contact those listed if they wish further information about the subject discussed in the text.

Garbisch, Edgar W., Environmental Concern, Inc., P.O. Box P, 210 West Chew Avenue, St. Michaels, MD 21663

F.1 INTRODUCTION

This appendix details the current knowledge on soils in wetland creation. While a wealth of knowledge exists on wetland plants, and some information on wetland hydrology, there is, unfortunately, a scarcity of literature on the role or importance of soils in wetland replacement.

The physical and chemical composition of a wetland substrate can be vital as a medium for plant growth. Soil texture, acidity, salinity, and other factors can be important considerations in the establishment of plants. However, experience has shown that in most situations, existing soils at the replacement site will probably be quite suitable for plant establishment. As such, the importance of soils is usually overstated as a limiting factor in wetland replacement (Erwin 1989).

In nature, human intervention is not needed to create a wetland. Topsoils are not imported to a natural wetland as a soil supplement. Soils are neither amended with organic material before a freshwater marsh is formed, nor do materials need to be added to change soil texture and permeability. More important to wetland vegetation establishment, regardless of the substrate, is establishing suitable hydrologic conditions.

SOILS & WETLAND REPLACEMENT

Soils are not usually a limiting factor in wetland replacement.

Soils are an important consideration in wetland replacement only if:

- A unique wetland type is being created (e.g. a bog, pocosin, vernal pool, etc.).
- An unusual soil condition exists (e.g. acid soils, high salinity, etc.).
- The existing soils are too porous (sand), too impervious (clay), or nonexistent (bedrock).

A discussion of specific technical aspects of soils in wetland replacement and "common sense" recommendations are presented in the following four sections:

- **F.2 Substrate Requirements:** Describes the importance of selecting suitable material and of soil chemistry to plant establishment.
- **F.3 Soil Recommendations:** Presents proven practices in wetland replacement projects.

- **F.4 Using Soil Seed Banks in Wetland Creation:** Explores the use of seed banks in wetland creation.

- **F.5 Special Soil Considerations For Specific Wetland Types:** Highlights important soil considerations when replacing specific wetland types.

F.2 SUBSTRATE REQUIREMENTS

F.2.1 FACTORS AFFECTING SUBSTRATE SUITABILITY

Soil is not usually the limiting factor in wetland replacement. However, several factors may need to be considered when evaluating substrate adequacy, such as the presence of soil contaminants, soil texture, or organic content. Most importantly, the substrate must have a sufficient water storage capacity to support the vegetative community, while still maintaining a texture that facilitates root penetration when not compacted. If the soils of the wetland replacement are determined to be inadequate (e.g. too porous, clayey, or contaminated), these inadequacies may need to be corrected as described below.

In the Research Team's opinion, too often wetland replacement plans needlessly specify the stockpiling and backfilling of topsoil in wetland replacement areas or fail to distinguish whether the backfilling of topsoil is necessary as a growth medium or as a seed bank to promote vegetation establishment. Such imprecise specifications can unnecessarily increase the overall cost of the replacement project.

SUBSTRATE REQUIREMENTS

In the Research Team's opinion, stockpiling and backfilling topsoil generally is unnecessary for wetland replacement sites. The substrate must have sufficient water storage capacity to support the specified vegetation.

F.2.1.1 Soil Contaminants

In industrial, agricultural, or heavily populated areas, soil or dredged material may contain contaminants such as pesticides, heavy metals, or petroleum, all of which can be detrimental to plant growth. These and other toxic materials can cause the failure of a wetland replacement project. The potential for plant uptake and release of contaminants into the food web is another concern, since these toxins can harm organisms that feed directly on plant materials. The presence of toxic materials should always be considered when locating a site for a wetland replacement project or securing soil from another location (Chapter 2).

F.2.1.2 Soil Texture

Soil texture refers to the relative proportions of sand, silt, and clay in a particular soil. Although some experts consider soil texture to be the most important soil characteristic to consider in wetland replacement, wetlands and wetland vegetation occur naturally and can be created on diverse soil types and textures.

It is also important to understand that the proportion of textural separates (i.e. sand, clay, silt) cannot be readily altered, nor is it usually necessary. Depending upon the wetland type, the functioning of a specific wetland type may alter the substrate texture naturally. For example, for most upland and some seasonally and irregularly saturated wetlands with a clayey or sandy soil textural classification, soil texture will not be altered by the functioning of the wetland ecosystem over time because of the regular decomposition of accumulated organic matter. For more permanently saturated wetlands which commonly have anaerobic soil conditions, the low rates of decomposition—coupled with the high rates of subsurface biomass production—can change the overall consistency of a soil in just a few growing seasons (Appendix I.2.16). Thus, depending upon the wetland replacement type and hydrologic conditions at the replacement site, changing the existing soil texture may be unnecessary.

As in upland soils, the most suitable wetland soils for plant growth will consist of medium-textured classified soils (e.g., loams, silt loams, or silty clay loams), with very few large fragments (Jansen and Melsted 1988). These soils provide a higher water storage capacity for vegetation growth. In addition, they:

- Are soft and friable, making implementation of the replacement wetland easier
- Permit easier penetration of roots and rhizomes, unless compacted
- Usually have adequate nutrients
- Provide good water and gas circulation

In spite of the above advantages, most common substrates are suitable for wetland replacement, except as described below (Hammer 1992).

Soils should have a sufficient amount of clay (20 - 30%) or organic matter (Section F.2.1.3) to act as a binder to enhance soil structure, storage, and the release of nutrients. Soils with too much clay, especially when compacted, may lead to poor root and rhizome penetration. Also, this will usually lead to poor aeration and a low hydraulic conductivity, restricting water availability for plants. For example, in Aiken, South Carolina, transplanted emergent vegetation was not able to penetrate the hard red clay subsoil it was planted in, thus limiting root growth to within the planting holes (Pierce 1989).

Gravel has been found to be a generally unsuitable substrate for many wetland replacement types because of its hardness, lack of nutrients, and low water holding capacity. Gravel was found unsuitable for tidal salt marsh creation on the Pacific coast, due to its hard surface (Josselyn et al. 1989). In Green Bay, Wisconsin, portions of two wetland restoration projects were dug in gravel fill and were determined later to be too hard and dry to support wetland vegetation (Owen et al. 1989).

Gravel has been found to make a suitable substrate for wetland replacement in low energy, tidal situations where the plants will not be scoured by the gravel and where the substrate remains saturated, i.e. does not dry out (Garbisch, personal communication). A tidal or nontidal wetland with a gravel substrate will support a different microbial and benthic community than a wetland on a peat or loam substrate. Gravel substrates have also been successfully used in the creation of wetlands for wastewater treatment (Steiner and Freedman 1989), since gravel allows for relatively unrestricted below ground flow of wastewater, while physically supporting the plants (Garbisch, personal communication). It also has been used in a stormwater retention basin in Hopkinton, Massachusetts, where *Pontederia cordata, Sparganium americanum,* and *Sagittaria latifolia* were all planted in a substrate of pea gravel with no sand or silt (Pierce 1989). Their success has been hypothetically attributed to their water supply, "which may have been a nutrient-rich hydroponic medium."

POSSIBLE PROCEDURE FOR EVALUATING SOIL INFILTRATION RATES

- A six-inch diameter test hole is dug or bored to six inches below the proposed elevation of the bottom of the wetland. In order to expose uncompacted soil, the sides of the hole are scraped with a sharp instrument, and the loose material is removed from the hole. Two inches of ½" - 3/4" gravel is placed in the hole to protect the bottom from scouring when water is added.

- The hole should be carefully filled with at least 12" of water. Care should be taken not to allow water to run down the sides of the hole. To facilitate this, a funnel with a hose attached may be used. The water level should be maintained for at least eight hours, and with a clay soil, preferably overnight. This is to ensure that the soil has completely swelled so that accurate results can be obtained.

- Any soil that has fallen into the hole during the soaking period should be removed. The water level should then be adjusted to six inches above the gravel (8" above the bottom of the hole). Immediately after adjustment, the water level is measured using a fixed reference point. Every eight hours the water level is measured again. After the measurement, the hole is refilled to the 6-inch level. This procedure is repeated until two successive water level drops do not vary by more than 1/10". At least three measurements should be made. The last water level drop is used to calculate the infiltration rate.

- The infiltration rate is expressed as inches/day. Thus the rate is calculated by dividing magnitude of the last measured water level drop (e.g., 1.1 inches) by the sampling interval (e.g., 8 hours). The resultant number is multiplied by 24 (the number of hours in a day) to get the infiltration rate.

  For example: $1.1 \text{ in} \div 8 \text{ hrs} \times 24 \text{ hrs/day} = 3.3 \text{ in/day}$

- Since this procedure was adapted from one used to design septic systems, no hard and fast rules exist to establish how many separate tests should be done when designing a replacement wetland. When designing a septic system, the U.S. EPA guidelines recommend three tests per area (in the mid-Atlantic this is generally 5,000 - 10,000 sq ft). This density of sampling is probably not needed in the site selection process. Three to five samples per acre will probably be sufficient if infiltration rate between holes does not vary by more than three inches per day. The samples can then be used to calculate an average rate. If the differences in rate between holes is greater than three inches per day, a soil type change may be present, which will warrant more sampling. Infiltration rates of greater than five inches per day indicate that the wetland will probably have to be sealed, if the goal is to establish a perched water table.

Sand is often used as a substrate in tidal wetland creation and has both advantages and disadvantages. The mechanical aspects of a replacement project, such as grading and planting, are usually easier in sandy soils due to a greater bearing capacity and trafficability than that of silts or clays (Broome 1989). The main disadvantages of sandy soils are their erodibility in high energy environments and their low nutrient retention (adsorptive) capacity. Broome (1989) states that the lack of nutrients is not usually a problem in tidal water regimes where water is rich in nutrients and the deposition of nutrient-rich sediments often occurs. A sand and peat mixture was used on wetland replacement projects in Wisconsin (Owen et al. 1989): water percolated through the peat/sand substrate much faster than through a natural peat, and the peat/sand substrate had less capacity for holding water. This subjected the vegetation to stressful, drought conditions.

LIMITS OF SANDY SOIL

Sandy soils are highly erodible in high energy environments and have low nutrient retention capacity.

Since wetlands occur naturally and can be created on diverse soil types and textures, specifications requiring the stockpiling and backfilling of topsoil in wetland replacement areas are usually not necessary. However, in acidic or other unusual substrates, this specification may be necessary (Section F.2.2.2).

F.2.1.3 Organic Material

The organic matter content of mineral soils is typically a small percentage by weight (Brady 1984). However, the organic matter content has a much greater influence on soil properties than its small percentage would indicate. Soil organic matter (Brady 1984):

- Is largely responsible for the loose, manageable structure of soils
- Is a major source of phosphorus and sulphur for plants
- Increases the amount of water a soil can hold, including plant-available water
- Is the prime energy source for soil organisms

However, even with the above important properties, the organic matter content of soils is generally a consideration only for those wetland replacements designed to have seasonal or irregular inundation or saturated soils versus wetland replacements where the soils will be regularly, semipermanently, or permanently saturated. This is because the anaerobic conditions that develop for the latter wetland replacement types usually cause a low decomposition rate and a rapid accumulation of subsurface biomass, making organic amendments unnecessary.

Recent studies have shown that where the above situation occurs, the amount of subsurface biomass for most herbaceous wetland plants is 50 - 60% of their total biomass (Appendix G). Megonigal and Day (1988) found that subsurface biomass was almost three times greater than above ground biomass in four seasonally flooded forest communities of the Dismal Swamp. In New Jersey, Smith et al. (1979) reported on a *Spartina alterniflora* marsh that produced eighty-two percent of its biomass belowground. Howes et al. (1985), citing a subsurface biomass study by Valiela et al. (1982), reported that "90% of the organic input to these sediments results from belowground production of *S. alterniflora*." Howes' own study reported that more than ninety-five percent of the total carbon input to these sediments is buried biomass, with some being decomposed within the sediment to CO_2. Bernard and Fiala (1986) showed that the belowground biomass of three *Carex* species ranged from 1.8 to 5.2 times greater than the aboveground biomass.

This is not the case for seasonally or irregularly inundated or saturated soils where organic matter is a transitory property. It is continually decomposed by microorganisms and replenished by local micro- and macroscopic flora and fauna. Therefore, under certain conditions described below, adding organic matter may serve a useful purpose. For example, organic matter is particularly important in the A and B soil horizons (Table F-1, below, "Soil Horizon Nomenclature") where many plant nutrients are stored. During rain storms, soils low in organic matter are more likely to seal over, causing low infiltration rates and crusting upon drying. This has been confirmed by Clewell and Lea (1989), who recommend incorporating organic material into the soil by discing a cover crop or adding sludge prior to revegetation to avoid soil crusting.

Clewell and Lea (1989) have also reported that during phosphate mining reclamation, the addition of organic matter to clay and sand (which has been brought to the surface and mixed) reduces or eliminates hardening of the soil mixture which would inhibit root extension and tree growth. Also, finely textured soils containing low organic matter can have unstable soil structure and low infiltration rates, resulting in a high rate of surface runoff and erosion (Jansen and Melsted 1988). Adding organic matter can reduce this problem.

When clay is missing from a soil, or constitutes a very small percentage, its properties can be substituted by the addition of organic matter to increase soil-water retention, provide nutrient exchange and storage capacity, and stabilize soil structure. This is not usually necessary where the wetland replacement type will result in a large production of belowground biomass.

F.2.1.4 Use of Organic Soils

A debatable issue in many replacement projects is the use of an organic soil, such as peat or muck, instead of a mineral soil that has a percentage of organic material. The use of an organic soil depends on the desired goals of the project.

Various peats can have different levels of acidity and nutrients, according to Brady (1984). Mossy peats are usually quite acidic with low levels of phosphorus and nitrogen, while sedge peats have intermediate nutrient levels and acidities. Cattail peats have relatively low acidities and a more even nutrient balance than mossy and sedge peats, but they are also coarser than the other two. The water-storage capacity of mossy peat is much higher than that of sedge peat, which is somewhat higher than that of woody peat. The residual woody material in the peat, however, produces a field soil that is an excellent medium for plant growth.

SOIL AMENDMENTS

Organic amendments are usually unnecessary in wetland replacement projects due to the organic material naturally produced in wetland substrates.

TABLE F-1

SOIL HORIZON NOMENCLATURE
(Summarized from Brady 1984 and Fanning and Fanning 1989)

One of the two current methods of classifying the layers (horizons) in a soil profile is the ABC system. This system, a "code" permitting rapid communication about soil morphology and genesis, is useful in generating soil descriptions in the field. A series of master horizons are recognized by the capital letters (O, A, E, B, C, & R). These are sometimes modified by lowercase letters which indicate specific kinds of master horizons. The following soil horizons occur in descending order in relation to soil depth; however, not all of these layers may be present in a soil profile:

O Horizon:	Composed of organic soil materials; the uppermost layer
A Horizon:	Composed of mineral materials which have been strongly darkened by the humified organic matter above it
E Horizon:	A mineral horizon from which silicate clays, iron, and aluminum have been leached
B Horizon:	A layer which forms below the O, A, and E horizons and is characterized by an accumulation of clays and hydrous oxides from upper horizons
C Horizon:	A zone relatively unaffected by soil-forming processes and lacking the properties of an A or B horizon
R Horizon:	Underlying consolidated rock

If an organic soil is used, then the disadvantages (Hollands 1989) and difficulties of their use must be understood:

- **Excavation:** Excavating organic soils often destroys their structure, leaving them in a deconsolidated condition which can cause newly planted vegetation to fall over or float away. This deconsolidated condition is similar to that of animal eatouts (McIninch and Garbisch 1991). McIninch and Garbisch (1991) concluded that certain wetland species (*Scirpus*, *Spartina*, and *Typha*) are sensitive to oxygen deficiency, which explains why these species often do not overwinter in highly saturated, poorly drained anaerobic soils such as those produced when a regularly flooded organic soil loses its structure due to excavation or animal depredation. This may have an impact on the overwintering of plant propagules in a replacement wetland with organic soils. (Appendix I.2.15)

- **Stockpiling:** If the soil is to be stockpiled instead of used immediately, wind or runoff erosion problems may occur. To prevent these problems, erosion and sediment control measures may be required, resulting in added project costs.

- **Nutrient content:** Organic soils can prove difficult for plant establishment, since they are nutrient deficient.

- **Organic matter decomposition:** If the organic soil is placed in a replacement wetland that is seasonally or irregularly flooded, then it is likely that the soil may dry out for part of the growing season. If a drought were to occur, decomposition of the organic material can be quite rapid, often more than one centimeter per year (Fanning and Fanning 1989). Upon drying, the peat, whose structure has usually been destroyed by excavation and compaction, may be subject to severe wind erosion and to the danger of ignition (Brady 1984).

- **Soil stabilization:** If an organic soil is placed in a wetland replacement project which is regularly, semipermanently, or permanently inundated, problems may occur due to the wet conditions. Low-load tracked equipment is usually required to place saturated organic soils in a replacement wetland, which are then difficult to stabilize.

- **Water quality:** Water quality may also be affected, depending on the characteristics of the organic soil used.

A common misconception is that organic soils have a much higher capacity to supply plants with water than mineral soils. Although organic soils have a higher water storage capacity on a weight basis, a given volume of organic soil would probably not supply vegetation with much more water than the same volume of mineral soil because organic soils have more unavailable water and they are lighter than mineral soils (Brady 1984).

Although it is obvious that care must be taken when specifying the re-use of organic soils, some situations involve exceptionally porous substrates—here it might be useful to backfill a replacement project with an organic soil to prevent rapid drainage. For example, Pierce (1989) describes a wetland (created for the mitigation of a highway project in Bourne, Massachusetts) which experienced an early spring drawdown in its first full growing season. The native sandy soil would have dried out, limiting the establishment of wetland vegetation or requiring watering, but the placement of an organic soil within the basin was vital in raising the soil's water retention capacity, thus maintaining sufficiently wet conditions to support both planted and volunteer vegetation.

Organic soils, as with mineral soils, contain seed banks and root stocks (of both desirable and undesirable plants) and can reportedly provide rapid revegetation of replacement wetlands. This process, often called "topsoiling" or "mulching," is a complicated subject covered in greater detail in Section F.4. Peaty soils are best to use only if the goals of the replacement wetland include bog-like conditions or acidophilic vegetation (Hammer 1992).

F.2.2 SOIL CHEMISTRY

Although the edaphic and chemical requirements of most trees, shrubs, and the more commonly used herbaceous plants are well-known, many of the plants commonly used for wetland creation have poorly understood chemical requirements. Consequently, the use of fertilizer is usually required to increase soil fertility to aid in plant establishment. Also, soil chemistry factors, such as acidity and salinity, can have a dramatic impact on wetland plant establishment. Each of these is discussed in some detail below.

F.2.2.1 Fertilizer Use

When creating a wetland, whether it is on dredged material, an existing substrate, or the lower horizons of an excavated substrate, the necessity for fertilization depends on the inherent fertility of the soil and the amount of nutrients provided by the replacement wetland's water supply. Incoming water with inadequate or excessive nutrient content may limit growth and development. Nitrogen is often the limiting factor in cordgrass marshes, since any nitrates present in the anaerobic soils are subject to denitrification and loss to the atmosphere (Broome 1989). Replacement projects often specify fertilization at the initiation of a new wetland system. The designers often assume that since terrestrial fertilization works well, adding nutrients will benefit wetlands also. Broadcast applications of fertilizer have been successful in seeded tidal marsh projects where the fertilizer is applied at low tide (Garbisch, personal communication). However, in nontidal projects, broadcast applications of common water soluble fertilizers are quickly taken up by any algae which may be present, leaving little for the targeted vegetation (Hammer 1992).

Garbisch (1986) recommends using a controlled release fertilizer, placed below the soil surface, which performs well under saturated soil conditions (Appendix G). This is supported by Broome (1989), who reports in an experiment with transplanted cordgrass, that results from OSMOCOTE[R] and Mag Amp[R], two slow-release fertilizers, were significantly better than the soluble materials, ammonium sulfate and concentrated superphosphate. Broome goes on to say that although phosphorus is abundant in many fine- textured sediments, applications of nitrogen and phosphorus fertilizer produce more growth than nitrogen alone.

Fertilization in the creation of seagrass communities is helpful in areas with little (less than two percent) or no organic matter, according to Fonseca (1989), but no reduction in planting density should be specified. In Florida, no controlled studies have been conducted to demonstrate the effects of fertilizer on mangroves, and until such evidence proves otherwise, fertilizer does not appear essential to mangrove establishment (Lewis 1989).

In forested wetland replacement in the southeastern United States, fertilization (possibly via a nurse crop) is often necessary to keep small, young trees from becoming suppressed by weeds, shrubs, and woody vines (Clewell 1989). Discing the weeds is another method to avoid competition; however, Haynes and Moore (1988) report that because of the greater costs involved with discing, fertilization is more feasible economically.

F.2.2.2 Soil Acidity

Naturally occurring soil acidity is common in any region where enough precipitation occurs to leach substantial amounts of exchangeable bases from the soil (Brady 1984). Acidic soils also occur in association with acid sulfate soils and acid mine drainage when, in the absence of calcareous materials, certain sulfide minerals are exposed to oxidizing environments (Caruccio et al. 1988). There has been very little study on the use of lime to reduce pH under wetland conditions.

Wetland creation projects often involve the grading of upland sites into flat, depressional areas more suitable for wetland habitat. This process commonly involves excavation into the B or C horizons of the soil profile which, especially in the southeast, can be acidic and deficient in plant nutrients (Broome 1989). One alternate remedy to this problem is to separate the topsoil from the excavated materials and stockpile it. The site is excavated below its designed elevations, and the stockpiled topsoil is backfilled to bring the area to its final grades. This is one example where it may be necessary to specify the stockpiling and backfilling of topsoil.

Another alternative is to identify the pH and amount of nutrients in the new substrate and add lime and fertilizers as needed. At a wetland creation site in North Carolina, extremely acidic soils (pH 2.5) developed over 25 percent of the area (Broome 1989). During site excavation, substrate which contained sulfides and yellow incrustations of jarosite, an iron sulfate mineral (also known as cat clay), was exposed to the atmosphere and subsequently underwent oxidation, thus lowering the pH. The marsh plants were unable to survive in areas with a pH below 3.0. Lime, a common soil amendment used to raise pH, was added to the substrate at a rate of 26,900 kg/ha (24,000 lbs/acre). The lime, according to Broome (1989), in conjunction with the tidal flushing and soil saturation, raised the pH above 4.0, and marsh vegetation was successfully established.

Another example of liming involved adding chicken manure, rock phosphate, and crushed limestone to a forested wetland in Mississippi (Lee et al. 1983). These amendments increased the pH from 2.9 to 5.5, and tree and shrub survival improved.

If lime must be used to correct an acidity problem, other beneficial effects may also occur (Donahue et al. 1983). An increase in pH by liming may also:

- Eliminate excess (toxic) soluble aluminum
- Increase microbial activity
- Reduce excess soluble manganese and iron
- Add calcium and magnesium to the soil if dolomitic limestone is used
- Increase available phosphorus
- Enable potassium to play a more efficient role in plant nutrition
- Create a more favorable environment for microbes which decompose organic matter, thus increasing available nitrogen
- Increase available molybdenum, an important trace element

CORRECTING pH

If pH is low, consult the local extension service for recommendations regarding rate of lime application.

As with the use of organic matter (Section F.2.1.3), the use of lime or other techniques probably applies most to seasonally or irregularly saturated soils than to substrates that are constantly anaerobic. Very little study has been completed on the liming of soils under regularly, semipermanently, or permanently flooded conditions.

According to Gambrell and Patrick (1978), the pH of acidic soils tends to increase when they are flooded. Flooding provides a reducing environment. Decreasing pH values upon exposure of a subsurface soil to air is often a good indicator of acid sulfate soils. Difficulties with these soil types can be avoided by maintaining soil saturation, thus preventing oxidation and promoting reduction.

F.2.2.3 Soil Salinity

High soil salinity can affect vegetation in the same manner as drought (Jansen and Melsted 1988). Salts cause drought stress by raising the osmotic pressure in the soil. This inhibits water uptake in many plants and may cause water to flow from the plant cells into the soil. Although it varies, the osmotic pressure of cell sap is usually higher in tidal wetland plants than in upland plants. The higher the osmotic pressure, the higher the salinity resistance.

Salinity does not usually reach toxic levels in sandy substrates in regularly flooded marine wetlands, since the salinity in these soils tends to remain relatively close to that of the surrounding water (Woodhouse and Knutson 1982). However, salinity in estuarine replacement sites can vary widely and may have to be monitored

MONITORING SALINITY

It may be necessary to monitor salinity before designing a vegetative community because salinity in estuarine systems can vary widely.

before a vegetative community is designed. Salinity can be problematic in irregularly flooded, high marsh communities which can develop into highly concentrated salt barrens upon which nothing will grow if not drained properly (Lewis 1989). This condition is usually limited to poorly drained areas that are flooded by storm tides. Salt damage can also be a problem in bays and sounds subjected to wind patterns during hot weather which result in extended periods of low water (Woodhouse and Knutson 1982)(Appendix I.2.6).

Salinity is also problematic in strip mine soils of the western coal mining region. The presence of salts in the overburden and a lack of precipitation inhibit vegetation establishment. According to Jansen and Melsted (1988), salinity problems can only be reduced by using low or salt-free materials to construct a new soil and by designing a favorable structure that creates a high water-holding capacity.

F.3 SOIL RECOMMENDATIONS

The following recommendations are based on the proven experience of wetland creation experts and summaries of key points made in the previous section:

- Almost all substrates have a growth medium potential for wetland replacement. The only ones that have proven completely unsuitable are bedrock, for obvious reasons, and dense clays, which usually act as a barrier to roots (Lewis 1989 and Carothers et al. 1989). In addition, clays have a strong soil water retention capacity that can inhibit plant uptake of water, even though the clay may be holding sufficient quantities of water. The soil must have a texture that, when uncompacted, promotes root penetration and a porosity for sufficient water storage to support vegetation (Gore and Bryant 1988). Possible problem soils include: surface-mined areas, industrial areas, and poorly drained sites that may have problems with toxic materials, pH, or salinity.

- Since most substrates can be used as a medium for plant growth, and thus wetland creation, it is usually unnecessary to specify their removal and backfilling with topsoil in the plans and specifications. This unnecessary site preparation adds to the cost and over complicates most projects. Of course, in situations where the soils are unsuitable due to the presence of unusual substances (toxic materials, ash, salts, acidity, etc.), it may be necessary to use this method.

- A slow-release fertilizer to assure good initial plant growth should always be used in wetland replacements when plant materials are installed. This applies to both herbaceous and woody material. According to Garbisch (1986), OSMOCOTE® is a commercial fertilizer that has been found to release nutrients, as designed, under saturated soil conditions over approximately the time frame specified. Three time-release formulas are available that can be bagged for planting underwater. An alternate fertilizer, AGRIFORM®, can be used when planting underwater without the use of burlap bags. (See Appendix G for more information on fertilizers.)

- When planting herbaceous wetland vegetation, soil amendments are not generally recommended. The annual subsurface biomass for most wetland vegetation is high (fifty to sixty percent of the total biomass); therefore, organic soil amendments are unnecessary due to the amount of organic matter that is rapidly produced within the substrate. (See Appendix G for more information on this topic.)

- Since trees and shrubs do not produce the same amount of subsurface biomass as herbaceous plants, organic soil amendments have been found to be advantageous for tree and shrub establishment. Equal parts of soil and leaf or pine bark compost, along with recommended amounts of fertilizer, are the suggested soil amendments when planting woody plants. (See Appendix G for more information on soil amendments for trees and shrubs.)

- While most substrates will support the growth of wetland vegetation, they may not do so if they have been compacted (e.g., by construction machinery). Substrates to be vegetated should always be deconsolidated by ripping, plowing, rototilling, or discing prior to planting. This must be specified in the plans and specifications (Chapter 5).

- Soil permeability is a significantly more important issue in nontidal wetland replacement sites than in tidal sites. A highly permeable sand is not a limiting factor in tidal wetland creation because the wetland water source is predictable and, for all practical purposes, inexhaustible. However, in nontidal areas, where the hydrology of many replacement sites depends at least partially on precipitation (direct and runoff inflows) trends, the presence of a highly permeable sand could cause drought conditions due to rapid infiltration (i.e., excessive outflows and subsequent draining of the wetland). It is recommended that soils in such wetland replacement sites have permeabilities closer to those of silts or silty loams whenever possible. If they do not, sufficient inflows must be available to compensate for these rapid outflows (Appendix E).

- If hydraulically dredged materials are to be used, predictions of expected settlement (consolidation) must be included for substrates composed of fine clays or silts. Such materials may remain in their slurry state for significant time periods, thus requiring a retaining structure for containment (Chabrek 1989).

F.4 USING SOIL SEED BANKS IN WETLAND CREATION

F.4.1 INTRODUCTION

The successful creation of a wetland usually requires the establishment of a relatively permanent vegetative community. This is normally accomplished by planting the desired species, using special seed mixtures, or allowing "volunteer" vegetation from adjacent wetland sites to colonize a created wetland naturally. Although seeding and transplanting can be expensive, allowing vegetation to volunteer takes an unpredictable amount of time. Alternately, a process called "wetland mulching," "topsoiling," or "mucking" is being used more frequently. This method, more clearly known as the seed bank method, uses soils from the impacted wetland as the seed source for vegetating the wetland being created. By transferring the upper layer of an existing wetland to a mitigation site with similar hydrologic conditions, a rich seed bank may be provided along with quantities of native rootstock. The micro- and macroscopic soil flora and fauna are also relocated this way. Finally, the upper layer of the replacement wetland's soil will have a native soil (organic or mineral) from an adjacent wetland.

The following sections provide a brief overview of basic soil seed bank ecology, problems of using seed banks in wetland creation, and requirements for establishing when the use of soil seed banks can be a reliable part of a plan.

> **SOIL SEED BANKS**
>
> Whereas wetland soils contain seeds, micro-organisms, and other plant propagules, studies of these soils have focused on seeds. Such soils have been named seed banks.

F.4.2 BASIC SOIL SEED BANK ECOLOGY

The term "seed bank" is defined in the *Guidelines* as all materials within the soil that could lead to vegetative establishment of a replacement wetland, including seeds, spores, mycorrhizae, tubers, and other propagules. This definition is consistent with that used by wetland scientists and experts who study wetland seed banks and recognize spores and propagules as a vital part of a wetland seed bank. Since most studies on wetland seed banks have addressed only the "seed" portion of what should more appropriately be called the "propagule bank," the information in this section is limited due to the lack of comprehensive propagule bank studies.

The composition and quantity of plant propagules in wetland seed banks differ within and between wetlands. These variations can be attributed to the following (Leck 1989):

- Seed germination traits and longevity
- Isolation and age of the wetland
- Seed rain (dropping of seeds from plants within wetland), dispersal (immigration and emigration of seeds), and seed predation
- Composition of the surface vegetation
- Hydrologic regime
- Other variations in the biologic and physical environment

In addition to these factors, how the soil is handled and stockpiled, e.g., length and manner of storage as well as exposure to the elements can affect its quality as a wetland seed bank. Each of these factors may play a part in a wetland seed bank, which makes predictable use of seed banks in replacement projects difficult. If project staff consider the use of seed banks, it is important for them to understand what is known about seed bank ecology.

Thompson and Grime (1979) identified four types of temperate herbaceous seed banks associated with certain morphological and physiological characteristics related to seed persistence:

- **Type I:** Annual and perennial species with a transient seed bank during the summer [examples include *Avicennia germinans*, *Rhizophora mangle*, *Acer rubrum*, *Populus* spp., and *Salix* spp. (Leck 1989)]
- **Type II:** Annual and perennial herbs colonizing vegetation gaps in early spring [*Impatiens capensis* and *Peltandra virginica* (Leck 1989)]
- **Type III:** Species germinating in autumn but maintaining small persistent seed banks [*Bidens laevis* and *Sagittaria latifolia* (Leck 1989)]
- **Type IV:** Annual and perennial herbs and shrubs with large persistent seed banks [*Juncus effusus* and *Dulichium arundinaceum* (Leck 1989)]

In a summary of wetland seed bank studies, Leck (1989) reports that wetland seed banks generally decrease in size and diversity as salinity increases but that seed banks with small size and low diversity occur in some freshwater wetlands as well. The seed banks are dominated by herbaceous species (van der Valk and Davis 1976) and, in fact, woody species are uncommon even in swamp seed banks (Schneider and Sharitz 1986, Gerritsen and Greening 1989).

A study of an Ontario lakeshore revealed that 81 percent of the germinated seeds originated in the top two centimeters of the lakeshore sediments (Nelson and Keddy 1983). In Illinois, Wilhelm et al. (1988) compiled data suggesting, though not conclusively, that the optimum excavation depth for relocating seed banks is 25 centimeters. Although numbers of seed decline as depth increases, McGraw (1987) found viable seeds at a depth of 45 centimeters. They were estimated to be 127 years old on the basis of age-depth relationships.

The composition of a freshwater seed bank with daily tidal fluctuation usually reflects the standing vegetation (Leck and Graveline 1979, Leck and Simpson 1987). Wetlands with seasonal hydrologic fluctuations exhibit a higher vegetative complexity, which is also reflected in the seed bank. An example of this is a prairie pothole (Leck 1989) in which mud flat species develop during droughts. As soon as normal rainfall resumes, the water eliminates the mud flat species, halts emergent species seed germination, and triggers the production of submerged and floating leaved aquatics. It is a cycle in which the vegetation and the seed bank contribute to each other. Seed germination in marshes is directly related to drawdown (van der Valk and Davis 1978). According to Leck (1989), the seeds of emergent perennials and mud flat annuals germinate under both inundated and drawdown conditions, while submergent species almost exclusively require flooded conditions to germinate.

F.4.3 IMPLICATIONS FOR USING SOIL SEED BANKS

It has become increasingly popular to specify the use of a donor soil from a nearby wetland (usually scheduled for impacts) as the substrate for the replacement site. This method entails collecting a donor soil prior to disturbance, stockpiling it, and applying it to the constructed wetland replacement area. Although a better alternative is to remove the donor soil and immediately place it in the replacement site, project timetables often make this impossible. Using a donor seed bank is reportedly the easiest and least expensive way to perform wetland mitigation. According to Leck (1989), "donor soils can be used to establish rapidly a species-rich vegetation dominated by native species that are adapted to local conditions." However:

> **SEED GERMINATION**
>
> Just because a seed is present in the seed bank does not mean that it will germinate in the replacement wetland.

- The donor soil may not produce identical vegetation to that of the donor site, since some seed viability may be lost during stockpiling.

- The seed bank composition may not be representative of the vegetative community at the time of soil collection.

- The seed bank is composed of the floristic elements that exist with the substrate (Wilhelm et al. 1988), but the actual vegetation that emerges will depend on the established moisture conditions as well as other seed germination factors.

- If the donor soil is organic soil, and its structure is destroyed during excavation, the overwintering of certain species could be inhibited (Section F.2.1.4).

Thus, the quality of soil seed banks depends on a number of factors, including how the soils are physically handled and stockpiled. Generally, if soil seed banks are used, the donor materials should be placed in the wetland as soon as possible, if the questions in Table F-2 have been addressed.

Although the use of the seed bank method has had few conclusive studies and raises many questions that should be investigated in greater detail, it should not be ignored as a potential vegetation establishment technique. Until more is known about this method, however, seed banks should not be the only method of vegetating a wetland replacement site. Wetland vegetation should be planted throughout 90 - 95% of a wetland replacement site, and the remaining 5 to 10% should be used as an experimental area to collect data on the best procedures for using soil seed banks.

Before the seed bank method can be specified as the sole technique for vegetating wetland replacement areas, the questions summarized in Table F-2 must be considered.

Seed bank studies can yield data on three features of new vegetation (Welling et al. 1988):

- Species composition
- Species abundance and distribution
- Environmental conditions which govern seedling recruitment

In order to make predictions on post-recruitment vegetation, however, an accurate examination of the donor seed bank's composition must be made.

Smith and Kadlec (1985) found that predictions for specific vegetation types were often inaccurate, but an approximate estimate of drawdown vegetation could be made for the entire area. According to Leck (1989), although predictions of seed bank composition based on greenhouse studies can be used to estimate the composition of post-disturbance vegetation, they cannot lead to quantitative predictions.

Using a donor seed bank involves the management of the seed bank for preferred species while controlling invasive vegetation. The same vegetative communities, including invasive species, will establish themselves each year if the same management practices are used annually. Large populations of desirable annual plants will usually become established using moist-soil management techniques in the first year of a summer drawdown, but a gradual increase of invasive species will take place if future drawdowns occur in a similar fashion (Leck 1989). Invasive vegetation can be controlled with various management techniques, including: burning, drying, flooding, irrigation, herbicides, plowing, or discing. Smith and Kadlec (1983) report in a study on a marsh immediately east of the Great Salt Lake that instead of a complete drawdown for marsh establishment, maintaining a water level of a few centimeters will allow the germination of many species, keep salinities low, and reduce the probability of invasive vegetation.

TABLE F-2

QUESTIONS WHICH MUST BE ANSWERED BEFORE SOIL SEED BANKS CAN RELIABLY PROVIDE VEGETATION FOR WETLAND REPLACEMENT PROJECTS

- ❒ What are the germination requirements of both preferred and invasive species?
- ❒ How can the field conditions be created that favor germination of preferred species?
- ❒ To what depth do viable seeds and plant propagules occur in various habitats, and to what depth should a donor soil be removed?
- ❒ How do seed production and pre- and post-dispersal predation affect the wetland vegetative community?
- ❒ What is the relationship between a seed's size and shape and its rate of burial and longevity?
- ❒ What is the optimal time of the year to collect the donor soil?
- ❒ Is sampling necessary to predict what vegetation will result from a donor seed bank?
- ❒ How can the donor soil be excavated and placed in the replacement site without damaging perennial plant parts through pulverization by machinery?
- ❒ At what thickness should the wetland soil be spread to assure germination of preferred species?
- ❒ How should water levels be managed to assure germination and seedling emergence of desired species?
- ❒ If the donor soil cannot be used immediately, then:
  - ❒ How should the soil be stockpiled?
  - ❒ What maintenance procedures are required to avoid problems such as freezing, destruction of plant materials from internal heat, oxidation of plant materials, or premature germination?
  - ❒ What are the time limits for the use of stockpiled soils?
- ❒ What is the relationship between the woody plant communities, their life histories and growth forms, and their dependence on seed banks?
- ❒ Does seed banking—as opposed to other landscaping practices—lead to the more frequent occurrence of undesirable plant species?
- ❒ Are the costs actually that much less in relation to the number of uncertainties in this method? Do the benefits associated with this process outweigh the risks and costs when compared to using existing subsoil and nursery grown plant stock?

F.5 SPECIAL SOIL CONSIDERATIONS FOR SPECIFIC WETLAND TYPES

Although soils are generally not a limiting factor in wetland creation, there may be exceptions in which soils become a major concern. Bogs are a good example, as they usually exhibit acidic, highly organic substrates that are often nutrient deficient and require acidophilic vegetation.

The vernal pools of southern California are also of potential concern. They have soils that typically formed in alluvial materials and are highly weathered with subsoils of clay (Zedler 1987). According to a study by Ferren and Pritchett (1988), a subsoil layer of clay with poor permeability is an essential component of any vernal pool creation. The vernal pools sampled in their study all show a subsoil clay content of greater than 23%.

Although the creation of seagrass meadows is highly impacted by water turbidity, soils can play a role as well. While seagrasses will usually grow in sediments ranging from mud to coarse sand, Lewis (1987) recommends that they have at least a 60-centimeter depth of deconsolidated sediments for healthy growth.

For successful prairie pothole establishment, backfilling with topsoil to final grades may be necessary because of the frequent occurrence of a yellow clay subsoil uncovered during excavation which inhibits root penetration. Without backfilling with topsoil, very little growth may occur outside the planting holes and no vegetation may grow if volunteering vegetation is expected.

EXPERIMENTAL USE OF SEED BANKS

Although experimentation with seed banks is encouraged, the Research Team recommends it should not be the only method used to vegetate a wetland replacement site. Experimental methods should be used on only a small portion (e.g., 5 - 10 %).

Other examples of unique regional wetlands which may require special attention to soils can be located in Appendix D, Wetland Enhancement and Wetland Restoration. Some of these examples include: pocosins, forested swamps, playas, and bottomland hardwood wetlands.

F.6 REFERENCES CITED

Bernard, J.M. and K. Fiala. 1986. Distribution and standing crop of living and dead roots in three wetland *Carex* species. Bulletin of the Torrey Botanical Club 113(1):1-5.

Brady, N.C. 1984. The Nature and Properties of Soils. MacMillan Publishing Company, New York, New York. 750 pp.

Broome, B.W. 1989. Creation and restoration of tidal wetlands of southeastern United States, pp.37-72. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Vol. 1. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Caruccio, F.T., L.R. Hossner, and G. Geidel. 1988. Pyritic materials: acid drainage, soil acidity, and liming, p.159-189. In L.R. Hossner (Ed.), Reclamation of Surface Mined Lands, Vol. 1. CRC Press, Boca Raton, Florida.

Carothers, S.W., G.S. Mills, and R.R. Johnson. 1989. The creation and restoration of riparian habitat in southwestern arid and semi-arid regions, pp. 359-376. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Vol. 1. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Chabrek, R.H. 1989. Creation, restoration, and enhancement of marshes of the northcentral gulf coast, pp. 127-144. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Vol. 1. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Clewell, A.F. 1988. Bottomland hardwood forest creation along new headwater streams, pp.404-407. In J.A. Kusler, M.L. Quammen, and G. Brooks (Eds.), National Wetland Symposium: Mitigation of Impacts and Losses. Association of State Wetland Managers, Berne, New York.

Clewell, A.F. and R. Lea. 1989. Creation and restoration of forested wetland vegetation in the southeastern United States, pp. 199-237. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Vol. 1. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Donahue, R.L., R. W. Miller, and J.C. Shickluna. 1983. Soils: An Introduction to Soils and Plant Growth. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 667 pp.

Emerson, F.R., Jr. 1961. Experimental establishment of food and cover plants in marshes created for wildlife in New York State. New York Fish and Game Journal 8(2):130-144.

Erwin, K.L. 1989. Freshwater wetland creation and restoration in the southeast, pp. 239-271. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Vol. 1. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Erwin K.L. and G.R. Best. 1985. Marsh community development in a central Florida phosphate surface-mined reclaimed wetland. Wetlands 5:155-166.

Fanning, D.S. and M.C.B. Fanning. 1989. Soil: Morphology, Genesis, and Classification. John Wiley and Sons, New York, New York. 395 pp.

Ferren, W.R., Jr. and D.A. Pritchett. 1988. Enhancement, Restoration, and Creation of Vernal Pools at Del Sol Open Space and Vernal Pool Reserve, Santa Barbara County, California. Environmental Report No. 13. University of California, Santa Barbara. 168 pp.

Fetter, C.W. 1988. Applied Hydrology. Merrill Publishing Company, Columbus, Ohio. 592 pp.

Fonseca, M.S. 1989. Regional analysis of the creation and restoration of seagrass systems, pp. 175-198. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Vol. 1. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Gambrell, R.P. and W.H. Patrick, Jr. 1978. Chemical and biological properties of anaerobic soils and sediments, pp. 375-423. In D.D. Hook and R.M.M. Crawford (Eds.), Plant Life in Anaerobic Environments. Ann Arbor Science Publishing, Ann Arbor, Michigan.

Garbisch, E.W. 1986. Highways and Wetlands: Compensating Wetland Losses. Federal Highway Administration, McLean, Virginia. 60 pp.

Gerritsen J. and H.S. Greening. 1989. Marsh seed banks of the Okefenokee Swamp: effects of hydrologic regime and nutrients. Ecology 70(3):750-763.

Gore, J.A. and F.L. Bryant. 1988. River and stream restoration, pp. 23-38. In J. Caims, Jr. (Ed.), Rehabilitating Damaged Ecosystems, Vol. 1. CRC Press, Boca Raton, Florida.

Hammer, D.A. 1992. Creating Freshwater Wetlands. Lewis Publishers, Chelsea, Michigan. 298 pp.

Haynes, R.J. and L. Moore. 1988. Reestablishment of bottomland hardwoods within national wildlife refuges in the southeast, pp. 95-102. In J. Zelazny and J. S. Feierabend (Eds.), Increasing Our Wetland Resources, Proceedings of a Conference. National Wildlife Federation, Washington, D.C.

Hollands, G.G. 1989. Regional analysis of the creation and restoration of kettle and pothole wetlands, pp. 287-303. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Vol. 1. U.S. Environmental Protection Agency. Environmental Research Laboratory, Corvallis, Oregon.

Howes, B.L., J.W.H. Dacey, and J.M. Teal. 1985. Annual carbon mineralization and belowground production of *Spartina alterniflora* in a New England Salt Marsh. Ecology 66(2):595-605.

Jansen, I.J. and S.W. Melsted. 1988. Land shaping and soil construction in reclamation of surface-mined lands, pp.125-136. In L.R. Hossner (Ed.), Reclamation of Surface-Mined Lands. CRC Press Inc., Boca Raton, Florida.

Josselyn, M., J. Zedler, and T. Griswold. 1989. Wetland mitigation along the pacific coast of the United States, pp. 1-35. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Vol. 1. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Leck, M.A. 1989. Wetland seed banks, pp. 283-405. In M.A. Leck, V.T. Parker, and R.L. Simpson (Eds.), Ecology of Soil Seed Banks. Academic Press, San Diego, California.

Leck, M.A. and K.J. Graveline. 1979. The seed bank of a freshwater tidal marsh. American Journal of Botany 66(9):1006-1015.

Leck, M.A. and R.L. Simpson. 1987. Seed bank of a freshwater tidal wetland: turnover and relationship to vegetation change. American Journal of Botany 74:360-370.

Lee, C.R., J.G. Skogerboe, D.L. Brannon, J.W. Linkinhoker, and S.P. Faulkner. 1983. Vegetative restoration of pyritic soils, pp. 271-274. In D. Graves (Ed.), Proceedings of 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. OES Publications, University of Kentucky, Lexington, Kentucky.

Lewis, R.R. III. 1987. The restoration and creation of seagrass meadows in the southeast United States, pp. 153-173. In M.J. Durako, R.C. Phillips, and R.R. Lewis (Eds.), Proceedings of the Symposium on Subtropical-Tropical Seagrasses of the southeastern United States. Florida Department of Natural Resources, St. Petersburg, Florida.

___. 1989. Creation and restoration of coastal plain wetlands in Florida, pp. 73-101. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science, Vol. 1.

McGraw, J.B. 1987. Seed bank properties of an Appalachian sphagnum bog and a model of the depth distribution of viable seeds. Canadian Journal of Botany 65:2028-2035.

McIninch, S. and E.W. Garbisch. 1991. Oxygen requirements of dormant wetland plants. Wildflower 4(1):6-12.

Megonigal, J.P. and F.P. Day. 1988. Organic matter dynamics in four seasonally flooded forest communities of the Dismal Swamp. American Journal of Botany 75(9):1334-1343.

Nicholson, A. and P.A. Keddy. 1983. The depth profile of a shoreline seed bank in Matchedash Lake, Ontario. Canadian Journal of Botany 61:3293-3296.

Owen, C.R., Q.J. Carpenter, and C.B. DeWitt. 1989. Evaluation of three wetland restorations associated with highway projects. Institute for Environmental Studies, University of Wisconsin, Madison, Wisconsin. Funded by the Transportation Policy Studies Institute, Wisconsin Department of Transportation.

Pierce, G.J. 1989. Wetland soils, pp. 65-74. In S.K. Majumdar, R.P. Brooks, F.J. Brenner, and R.W. Tiner, Jr. (Eds.), Wetlands Ecology and Conservation: Emphasis in Pennsylvania. Pennsylvania Academy of Science.

Robertson, S.D. and R.F. Witter. 1983. The effects of split-applied fertilizer treatments on growth and survival of sycamore and cottonwood planted on mine soils. In D. Graves (Ed.), Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. OES Publications, University of Kentucky, Lexington, 1983.

Schneider, R.L. and R.R. Sharitz. 1986. Seed bank dynamics in a southeastern swamp. American Journal of Botany 73(7):1022-1030.

Smith, K.K., R.E. Good, and N.F. Good. 1979. Production dynamics for above and belowground biomass components of a New Jersey *Spartina alterniflora* Tidal Marsh. Estuarine and Coastal Marine Science 9:189-201.

Smith, L.M. and J.A. Kadlec. 1983. Seed banks and their role during drawdown of a North American marsh. Journal of Applied Ecology 20:673-684.

___. 1985. Predictions of vegetation change following fire in a great salt lake marsh. Aquatic Botany 21:43-51.

Steiner, G.R. and R.J. Freedman, Jr. 1989. Configuration and substrate design considerations for constructed wetlands wastewater treatment, pp. 363-377. In D.A. Hammer (Ed.), Constructed Wetlands for Wastewater Treatment. Lewis Publishers, Chelsea, Michigan.

Thompson, K. and J.P. Grime. 1979. Seasonal variation in the seed banks of herbaceous species in ten contrasting habitats. Journal of Ecology 67:893-921.

Valiela, I., B. Howes, R. Howarth, A. Giblin, K. Foreman, J. Teal, and J. Hobbie. 1982. Regulation of primary production and decomposition in a salt marsh ecosystem, pp. 261-290. In B. Gopal, R. Turner, R. Wetzel and D. Whigham (Eds.), Wetlands: Ecology and Management. National Institute of Ecology, Jaipur and International Publications, Jaipur, India.

Valiela, I., J.M. Teal, and N.Y. Persson. 1976. Production and dynamics of experimentally enriched salt marsh vegetation: belowground biomass. Limnology and Oceanography 21:245-982.

van der Valk, A.G. and C.B. Davis. 1976. The seeds of prairie glacial marshes. Canadian Journal of Botany 54:1832-1838.

___. 1978. The role of seed banks in the vegetation dynamics of prairie glacial marshes. Ecology 59:322-335.

Wein, G., S. Kroeger, and G.J. Pierce. 1988. Lacustrine vegetation establishment within a cooling reservoir. In Proceedings of the 14th Annual Conference on Wetland Restoration and Creation. Hillsborough Community College, Hillsborough, Florida.

Welling, C.H., R.L. Pederson, and A.G. van der Valk. 1988. Recruitment for the seed bank and the development of zonation of emergent vegetation during a drawdown in a prairie wetland. Journal of Ecology 76:483-496.

Wilhelm, G., J. Mengler, and L. Squires. 1988. Des Plaines River Wetlands Demonstration Project: Seed Bank Study. The Morton Arboretum, Lisle, Illinois. 48 pp.

Woodhouse, W.W. and P.L. Knutson. 1982. Atlantic coastal marshes, pp.45-70. In R.R. Lewis (Ed.), Creation and Restoration of Coastal Plant Communities. CRC Press, Boca Raton, Florida.

Zedler, P.H. 1987. The Ecology of Southern California Vernal Pools: A Community Profile. Biological Report 85(7.11). U.S. Fish and Wildlife Service. 136 pp.

APPENDIX G
VEGETATION

In addition to the references cited at the end of this appendix, authors contacted the individuals listed below about their expertise on various wetland replacement topics. These contacts are noted in the text parenthetically as "(NAME personal communication)."

Clewell, Andre F., A. F. Clewell, Inc., 1345 University Parkway, Sarasota, FL 34243
Garbisch, Edgar W., Environmental Concern, Inc., P.O. Box P, 210 West Chew Avenue, St. Michaels, MD 21663
Josselyn, Michael N., San Francisco State University, Romburg Tiburon Center, P.O. Box 855, Tiburon, CA 94920
Rieger, John, District Biologist, Environmental Stewardship Branch, California Department of Transportation, P.O. Box 84506, San Diego, CA 93128-5406

G.1 PLANT CHARACTERISTICS

G.1.1 INTRODUCTION

Tables G-1 through G-9 list the dominant plant species from wetland types throughout the country. (These tables and Table G-14 are at the end of this appendix because of their length.) These plants are known to be available for and/or successful in wetland replacement projects. One or more of the following statements may apply to each:

- Reported as **planted** (not including those allowed to colonize or develop from seed banks) in previous wetland replacement or enhancement projects and found to have been successfully established

- Carried by a nursery that produces wetland plant material

- Recommended in planting guides or revegetation manuals issued by agencies such as the U.S. Department of Agriculture

Additional information is included for each species regarding water tolerances (frequency, duration and depth of flooding), salt tolerance, shade tolerance, wildlife value, national distribution, and possible plant material sources. The information used to develop Tables G-1 through G-9 and G-14 came from the many references listed in Section G.8 *References Cited and Bibliography*.

All species' names are verified by *A Synonymized Checklist of the Vascular Flora of the United States, Canada, and Greenland, Volume II: The Biota of North America* (Kartesz and Kartesz 1980). All plants listed in the tables are perennials unless otherwise indicated.

Most of the plant species included are native to their designated region (Table G-7, Species Range). Native plants generally should be used unless circumstances exist which require special adaptations or attributes which native plants may not have (Section G.2). It also has been suggested that when planting an area, only plants known to be historically present should be used in order to maintain the natural ecological integrity of the area (Josselyn, personal communication).

The criteria to be met before listing a plant in the tables may have led to the omission of some plants that may, to a local expert in the field, be seemingly obvious candidates for planting. Inadequate information resulted in a plant's exclusion: none are included with only partial information. Inadequate information may be due to 1) a lack of recorded data for projects that would allow a determination of their success, or 2) project failure, or 3) an insufficient post-project time period for drawing conclusions about vegetative establishment.

With further research and more detailed project and monitoring reports, it will be possible to refine and/or expand the tables.

Finally, since some vegetative species (purple loosestrife, reed canary grass) are considered invasive pests (noxious weeds) in some parts of the country but not in others, project personnel should consult their state's noxious weed list (NWL) to prevent the selection of any invasive or otherwise unwanted plant species for the replacement wetland (see invasive species listed in Tables G-1 through G-6 and G-8). The Research Team recommends that the use of invasive species usually should be avoided or minimized in wetland replacement. Some of the listed invasive species are on state noxious weed lists and therefore may be illegal to plant/propagate. They have been listed here to warn users of the manual that they are in fact considered invasive and can out-compete other wetland species rapidly to the point of dominating a wetland replacement project. Their use should be avoided.

G.1.2 PRIMARY TABLES

There are six primary tables organized on the basis of water tolerances (frequency, duration, and/or depth of inundation). They are: Tidal Saltwater, Tidal Freshwater, and four Nontidal Freshwater tables including: Semipermanently to Permanently, Regularly, Seasonally, and Irregularly Inundated or Saturated (Tables G-1 through G-6). The project designer should refer to the table that describes the type of wetland to be designed for plants suited to those conditions.

While plants are classified into five different hydrology types (as well as being divided into freshwater and saltwater species), many plants occur in more than one of these hydrologic regimes. Those which do can be found in all tables that describe conditions under which they are known to be planted successfully. Within each table, information regarding the type of hydrology that each plant can withstand is more specific.

All hydrology information in the tables is intended to be used as a general guide for wetland replacement design. Because local conditions vary (salinity fluctuations, rainfall, tidal amplitude, wind influence, etc.) and ecotypic variations in plants may cause differences in tolerances, biological benchmarks measured from surrounding, local vegetation should be used as guides for vegetation placement whenever possible (Chapter 2). The elevation ranges of plant communities in the area can be duplicated in replacement projects for successful establishment of similar communities.

Water tolerance ranges are given for many plants in the tables. These ranges should be used with some caution. Maximum depths and flooding frequency are indicated to show possible tolerance at a mature stage. When seeding is possible (Section G.7), germination and seedling growth may not be possible at maximum water depths. When planting immature emergent, shrub, or tree species, these plants must be tall enough to emerge above the surface of the water (refer to Section G.3), regardless of their depth tolerance as mature plants.

G.1.2.1 Tidal Tables (Tables G-1 and G-2)

There are two tables containing vegetation that can be planted in tidal areas. The Tidal Saltwater Table (Table G-1) lists plants that tolerate varying degrees of salinity. Those that tolerate higher concentrations of salt usually will grow in water of lower salinity, but they may not be able to compete as well with the species which normally grow in less saline water (Zedler 1984, Gosselink 1984). The Tidal Freshwater Table, Table G-2, lists plants that grow in freshwater systems that are subject to tidal fluctuations. Some plants are listed in both tables because they tolerate varying levels of salinity.

The two tidal tables are divided into three zones:

- High marsh—above Mean High Water (MHW)
- Intertidal—Mean High Water to Mean Low Water (MLW)
- Subtidal—below Mean Low Water

Tides on the Pacific Coast of the United States are mixed tides; that is, one tide is substantially higher than the other. Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW) are not specifically mentioned in the tables, although these elevations are often places where there is an abrupt change in plant community. It is strongly recommended that biological benchmarks be used to find the elevation ranges of plants growing throughout all elevations associated with tidal waters.

The area above MHW is described further by indicating how far above MHW species usually grow. The area defined as **A** is the area above MHW to the spring high tide. **B** is the area above the spring high tide extending to upland. **A and B** include both of these areas, and **B** alone means that this species probably does not tolerate the frequency of inundation found in the spring high tide area. These regions are defined only so that they may be used as guides. Again, the use of biological benchmarks is strongly recommended.

Many plants which grow in the intertidal zone (MHW - MLW) are limited to only a part of this zone. They are adapted to inundation frequencies and durations that occur only within certain tidal ranges. The range of elevations at which each plant is found is given as a percentage of the intertidal zone in the tables. For example, the upper 50% of the intertidal area means that the area of planting for this species is from the elevation of MHW down to the mid-tide elevation or the upper half of the intertidal range (MHW - MLW). The lower 25% is from the elevation of MLW up through the elevations that include 25% of the intertidal range. The use of biological benchmarks to verify these intertidal elevations is strongly recommended.

It is difficult to make a general statement defining how far below MLW submerged aquatic vegetation (SAV) will survive. (See also Appendix C for information on SAV beds.) The depth that the plants will tolerate usually depends on the turbidity of the water as well as other local conditions. It must be stressed that in the establishment of all seagrasses, water quality will be the critical factor for success. Seagrass **will not** survive in water that is too turbid for light to reach the submerged leaves (Fonseca 1992).

Plants sometimes grow in more than one of these three zones, in which case they are found in all appropriate locations on the table. Some species are biological indicators of these hydrologic elevations (MHW and MLW) in that they start or stop abruptly at one of them.

Elevation is important to vegetative establishment because it determines the frequency and duration of soil inundation. Plants not only respond to the length of time that their roots are flooded but also to soil properties that are influenced by duration and frequency of flooding. The proportion of time that salt marsh soil is not saturated has a strong effect on its salinity and pH. Irregularly flooded areas can build up salt in the sediments because evaporation leaves the salt behind. Aerated marsh soils can also lead to oxidation of hydrogen sulfide which lowers the pH (Josselyn and Buchholz 1984). An influx of fresh water from other sources can influence both of these factors by diluting salts and decreasing time of aeration. Depending on how a plant (and its competitors) responds to salt concentration and other soil characteristics, these factors will affect where it will grow in the local water regime (Josselyn, personal communication). A plant's growth may expand well outside of its ordinary range or narrow considerably. Because of the many factors affecting salt concentrations, more than just an area's water salinity should be examined when choosing plants for saltwater areas.

While salinity tolerances are given in the Tidal Saltwater table (Table G-1) and in the Special Characteristics table (Table G-8), it should be noted that these are estimated ranges and that, for the reasons explained above, different combinations of salinity and elevation can cause confounding effects which may bring unexpected results. It is also important to consider that newly planted vegetation is more sensitive to salt concentrations than established vegetation (Zedler 1984, Broome et al. 1988).

Vegetation in freshwater tidal areas forms communities when located over large areas, although "distinct zonation is not readily apparent" (Odum et al. 1984). Species do have flooding depth and frequency preferences and occur in rough zones accordingly (Mitsch and Gosselink 1986).

G.1.2.2 Nontidal Tables (Tables G-3 through G-6)

The classification of the following four water regimes is based on hydrologic zones defined in the *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987) which is adapted from Clark and Benforado (1981). These "zones" are distinguished by the duration of inundation and/or saturation **during the growing season** (flooding during the dormant season does not have a significant impact on vegetation).

- **Semipermanently to permanently:** area is inundated or saturated from 75% to 100% of the growing season
- **Regularly:** area is inundated or saturated from 25% to 75% of the growing season
- **Seasonally:** area is inundated or saturated from 12.5% to 25% of the growing season
- **Irregularly:** area is inundated or saturated from 5% to 12.5% of the growing season

Depth tolerances of species are given in Tables G-3 and G-4.

Many plants that grow in water over one foot deep develop morphological adaptations to deeper water. If these species break dormancy and grow in shallow water (e.g., water at the surface), they often will not develop these special morphological features that are found when they break dormancy and grow in deeper water. When these shallow-water-adapted species are transplanted to deep water, they often will not survive. Vegetation must be grown in conditions similar to those in which they will be planted. If this option is not available at the supplying nursery, dormant stock should be planted during the dormant season so that when the plants break dormancy they will develop the necessary structures for survival.

WATER-DEPTH TOLERANCE

A project designer looking for a plant that will tolerate 0.5 ft of water should consider the plants that tolerate 0 - 1 ft, 0 - 2 ft, and deeper depths of water, as well as the 0 - 0.5 ft depth range, because the required depth falls within all of these ranges.

In Tables G-3 and G-4, some tree species are identified as occurring in a Riparian Water Regime. They generally tolerate standing water of some depth, though water depth is not, for the most part, a determining factor in the survival of many of these woody species (unless otherwise indicated by particular species being found in a specific depth range category). The duration and timing of flooding has a much more significant influence on woody species' survival. The duration of inundation they can tolerate is implied in the definition of the tables' titles: G-3, Semipermanently to Permanently Inundated or Saturated and G-4, Nontidal Freshwater: Regularly Inundated or Saturated.

While some woody species may tolerate flooding throughout most of the growing season, as seedlings they may not. Most woody species' seedlings are not as tolerant of permanent or regular flooding as older trees of the same species (Broadfoot and Williston 1973). These plants may need a number of growing seasons to become established and/or tall enough so that leaves are above the level of flooding (Whitlow and Harris 1979). Flooding tolerance is species-specific in that some species that leaf out later in the season will survive because the seedlings are dormant during flooding (Streng et al. 1989). If flooding occurs after leaf flush, however, seedling mortality may be high (Broadfoot and Williston 1973).

Some riparian woody species require swiftly moving water for survival or establishment. Success of such plantings may be limited by standing water (John Rieger, personal communication). Whitlow and Harris (1979) note that the literature suggests that aeration of floodwater may be a significant element in the growth of water tolerant woody species. Sedimentation by water carrying silt or sand can also increase mortality of seedlings (Broadfoot and Williston 1973).

No depth preferences are indicated in the Seasonally or Irregularly Inundated tables (Tables G-5 and G-6, respectively) because when the duration of flooding is as brief as in these two hydrologic regimes, the depth does not have a significant influence on the plants listed in these two tables. The species listed are also ones to consider for transitional areas (from wetland to upland) because of their tolerance to drought.

The concern about planting seedlings in a permanently or regularly flooded zone is not as important an issue in seasonally and irregularly flooded areas. Timing of planting is the most important factor for seedlings in these hydrologic zones (Clewell, personal communication). Planting should take place when growth can occur without flooding. Most flooding in seasonally and irregularly flooded areas occurs during the dormant season, providing a large window for planting time. Planting during drought periods should also be avoided (refer to Section G.6 for information on planting).

G.1.3 SECONDARY TABLES

After plants have been selected on the basis of the proposed wetland hydrology, a number of other characteristics should be addressed. The two secondary tables are for this purpose.

G.1.3.1 Species Range (Table G-7)

The Species Range Table (Table G-7) includes every species listed in Tables G-1 through G-6, along with its National Range of Indicators(s). These are taken from Reed (1988) and reflect the range of estimated probabilities of a species occurring in wetland conditions.

In the experience of the Research Team, it is important to a wetland project's success that plants be used that are known to flourish in the area where they are to be planted. The Species Range Table provides natural distribution information, indicating where species are found to grow throughout the country.

Most of the plants specified in the tables have wide distributions. Because varieties are not listed, the ranges of varieties are included under one species name. The Range column indicates where varieties of one species are known to exist. Although some varieties of the same species may be found in slightly different ranges, nurseries do not usually specify varieties, and it is not known whether it is necessary to plant certain varieties in specific areas. Establishing which varieties would be most appropriate would be unreasonably difficult, and it is probably not necessary to do so. If plants are found not to have established properly during the monitoring period, they should be replaced at that time.

When the distribution of a plant includes a large portion of the country (an extreme example is one that would include the east coast and the west coast), it is very likely that ecotypes of that species exist. This means that a particular plant may be adapted to the conditions in a specific climate or geographic area (e.g., temperature, photo period) and, if planted in other climates or geographic areas, would 1) not survive, 2) look different, or 3) flower at a different time compared with local populations (Allen and Klimas 1986, Garbisch personal communication). When ecotypes are known to exist, effort should be taken to use plant materials from sources as close to the creation site as possible. Because it is often difficult, if not impossible, to know that ecotypes are present, these efforts should be made only when a plant is known to grow over a large area of the country. The existence of ecotypes is not well documented, so it may be a waste of time and resources to ensure that all plant material is local. Instead, plant material should be obtained from nurseries as close as possible to the replacement site. Whether or not it thrives will be discovered during the monitoring period. At that time, all unsuccessful vegetation should be replaced. Refer to Section G.2 for a more thorough discussion of this issue.

It is also true that as a result of ecotypic differences, some ecotypes may not be as well adapted to the particular conditions indicated in the tables. Knowledge of local plants and conditions will help to prevent losses due to ecotypic variance.

Hardiness Zones are given to show freeze tolerances. Zones were taken from the *U.S. Department of Agriculture Plant Hardiness Zone Map*. Although the 1965 version of the map may be more familiar, the newer map is based on more recent meteorological data and, therefore, supersedes the 1965 edition. For those familiar with the old map, new zone numbers cover areas similar to those covered by old zone numbers and so the zones may be considered to be the same. On the new map, the lower-case letters (a and b) simply subdivide the zones into two sections for further detail ("a" being the colder section and "b" the warmer) and can be disregarded if the new map is not available.

Plant suppliers can be found in nationwide and statewide source guides. Smith (1991) lists some examples of these guides such as *Andersen Horticultural Library's Source List of Plants and Seeds* and *Ethel Zoe Bailey Horticultural Catalog Collection*. In addition, the Army Corps of Engineers has published a *Directory of Wetland Plant Vendors* (Soil Conservation Service 1992) that users can consult for vendors in each state. Plant material can also be located through brokers, whose names are available from local nurseries. Care should be taken when using brokers to assure that the quality of plant material is suitable for wetland planting.

Nurseries that do not specialize in wetland plant supply may carry the species included in the tables. These nurseries may be used but with some caution. The plants propagated and/or grown in an upland-oriented nursery may not have been grown under hydric conditions. As a result, when they are planted in a wetland replacement site, the shock of hydric conditions may increase mortality. To prevent this, it may be necessary for these nurseries to grow the plants specially.

This may not be an important concern when locating plant material for a seasonally or irregularly flooded site, especially if most flooding takes place during the dormant season. Shock from planting under these conditions is unlikely for material obtained from nurseries dealing in upland plants.

There are some species not carried by nurseries. Thus, these species may have to be collected from a "donor site." Many precautions must be taken when using this method of plant supply. The donor site must have a hydrology very close to that of the wetland being created and it must be located in the same region as the site to avoid the ecotype problems mentioned above (Allen & Klimas 1986). Care must be taken to minimize impacts at the donor site, so that the plant population can recover within a reasonable period. Local regulations, which must be considered, differ on removing vegetation from other wetland areas. Special collection permits may be required. Problems may arise concerning the method of collection, type of propagule or transplant collected, time of the year to collect, storage during the interval between collection and planting, etc.

All of these factors vary depending on the species involved. This option can, however, offer plant material that is well adapted to survive in the planned replacement site, increasing chances of a successful project. Refer to section H.4 for a more detailed discussion.

Nurseries provide transplant materials in various forms. Certain forms are more preferable for use in wetland design. Containerized plants are probably the best to specify for most situations, but they may be prohibitively expensive. Balled and bagged trees can be unsound because the stresses caused by cutting off roots and by being placed in wetland conditions can increase the chances of mortality. The use of seed is only appropriate in certain situations (Section G.7). Refer to section H.3 for discussion on cost vs. probability of success as well as what forms are appropriate to plant in specific situations and/or specific times of the year.

G.1.3.2 Special Characteristics (Table G-8)

The Special Characteristics Table (Table G-8) summarizes available information about species listed in the primary tables. This table details plant habitat requirements and preferences to assist the designer in the placement of each species.

The Shade Tolerance column indicates which plants can tolerate full shading and only partial shading. The designer should orient various species with this in mind. Species intolerant to shading should be arranged on the plan so they are not overshadowed by other plants or structures.

The spreading rate of each species is necessary information for efficient spacing of the plants. The time required for vegetative establishment or cover to take place should be minimized, while also keeping the number of plants necessary as low as possible. The faster a species' rate of spreading, the more distance there can be between transplants.

For most trees and shrubs, spreading rate is not applicable. However, some species spread by sending out suckers, or shoots, that arise from the underground trunk or roots. Some shrubs are stoloniferous, sending out roots from the nodes of stems which run along the ground. These species have been identified as having a slow rate of spread as opposed to having no spreading capability.

The Salinity column is included in this table and in the Tidal Saltwater table (Table G-1) because there are a few species that generally occur only in nontidal situations but that have some salt tolerance. This information can be useful when a creation site is in an area that is subject to saline conditions (e.g., salting of roads).

The Other column contains miscellaneous information, such as pH tolerances, temperature tolerances, elevation tolerances, nitrogen fixing attributes, invasive tendencies, etc. It also provides information about soil, streambank, and shore erosion control characteristics. Generally, it can be assumed that any plant with rhizomatous spread has good erosion control capabilities.

G.1.3.3 Wildlife Value (Table G-9)

The Wildlife Value Table (Table G-9) gives available information on animals which use vegetation listed in the primary tables.

The Benefits Provided column indicates how certain animals use the plant species. This information can be used to determine whether this value is important to provide or whether it would be detrimental or counterproductive. For example, if a species of tree is used by deer for browsing and a creation or enhancement site is in an area with a large deer population, the species of tree may be undesirable for the project. If, on the other hand, one of the objectives of the wetland creation is to increase waterfowl habitat, it can be determined from this table whether the plants chosen for the creation site are valuable for cover, nesting, and food for waterfowl. This information will indicate not only that the material is beneficial as a source of food, but also that the site may need protection from wildlife degradation while new plants become established.

There are also a few species of plant that are indicated as **not** being favored by certain animals. When an emergent marsh creation site is located in an area where there is a large population of geese, it may be necessary to plant species that are not eaten by geese in order to maintain vegetative cover while other plants become established.

Limited information is available on specific plants that animals use. For this reason, the animal species given are most likely just examples of species that use specific vegetation. If only a few animals are listed as using certain species of plants, it is not necessarily because that plant has a low value for wildlife. It is more likely that other animals have not been identified which use that plant. Plants known to have a low value for wildlife are specifically noted as such in the table.

G.2 NEED TO USE LOCAL NATIVE PLANT SPECIES

A native plant species is defined as one originating or occurring naturally in a particular region, such as the Northeast or Southwest United States (Barnhart 1986; Dickerson 1991). The use of native plant species should always be specified for wetland replacement projects.

A local native plant species is defined as indigenous, endemic, or nearest neighbor to ones with wide geographical ranges (i.e., Northeast, Southwest) that will almost always develop locally adapted populations called ecotypes. Ecotypes result from the genetic responses of populations to habitats and are distinguished by morphological and/or physiological characteristics. Most wide-ranging species are composed of a continuum of ecotypes, each differing slightly in morphology and/or physiology.

Wetlands that will be impacted or lost due to highway projects generally will consist of native plant species, rather than exotic or introduced ones. Some exceptions include, but are not limited to, *Phragmites australis* wetlands throughout most of the United States (U.S. Department of Agriculture 1971) and *Spartina alterniflora* wetlands throughout coastal areas of the western United States (Aberle 1990).

The following questions arise when specifying plant materials for wetland replacement projects:

- How important is it for the use of local native wetland plant species to be specified?
- For what plant species is it important to use local native plant materials?
- What are the geographical constraints in obtaining plant species in order to assure that they are native to the wetland replacement site?

Answers to these questions are not known, even for a few plant species. This is not surprising, since very extensive research would be required to provide the answers for a single species.

Considering Example A, below, the answer to the first question above for the species *Spartina alterniflora* is "in certain circumstances, very important and in other circumstances, not important" (Garbisch personal communication).

This example illustrates that just for one species the answers to the above questions are not straightforward. Even though cordgrass is native to the Northeast, because of its ecotypes cordgrass from eastern Virginia can be considered to be local native to coastal areas of Virginia, Maryland, Delaware, New Jersey, New York, and Connecticut north to New Haven. And cordgrass from southern Maine cannot be considered local native to Maryland. To clarify further the above questions for cordgrass nationwide would be an immense and time-consuming effort.

EXAMPLES OF THE COMPLEXITY OF THE "NATIVE SPECIES" ISSUE

EXAMPLE A: *Spartina alterniflora* (cordgrass) is native to the East and Gulf Coasts; however, cordgrass from southern Maine (Portland) is an ecotype that produces an ecologically isolated community when planted in Maryland (approximately 500 miles separation). For example, in Maine and Maryland, the native species flower in August and September, respectively, and both ecotypes grow 4 - 5 feet tall and are visually indistinguishable. In Maryland, the Maine ecotype flowers in May, shortly after resuming growth from dormancy, and the flowering stems are no taller than 6 - 10 inches. New shoots are produced by the Maine ecotype during the balance of the growing season in Maryland, but all are shorter than the flowering stems. In Maryland, the Maine ecotype will never mix genetically with the Maryland ecotype; it will remain a stunted variety of cordgrass. Returning the stunted Maine ecotype to Maine, after being grown in Maryland for three years, leads to its return to normal height and flowering time during the first growing season.

Conversely, *Spartina alterniflora* from eastern Virginia (Assateague) has been planted throughout coastal areas of Virginia, Maryland, Delaware, New Jersey, New York, and Connecticut (New Haven) (400 miles separation) and has appeared the same and flowered during the same period as the local native species.

EXAMPLE B: To complicate the "native" issue further, Tiner (1991) suggests that there may well be ecotypes of FACU species that are adapted for life in wetland conditions. Tiner (1991, Table 3) cites phenotypic varieties of *Acer rubrum, Andropogon virginicus, Celtis laevigata, Fagus grandifolia, Nyssa sylvatica, Panicum virgatum*, and *Quercus falcata* that each have different tolerances to wetland conditions. For example, *Nyssa sylvatica* has upland, floodplain, and swamp phenotypes (Keeley 1979).

It is unlikely that the questions posed above will ever be answered authoritatively for more than a few plant species.

Examples A and B illustrate that the use of native plant species may not always be appropriate because there may be ecotypes and phenotypes among the natives that are undesirable to use or that are more suitable for wetland use than others.

Based on these examples, what guidelines can be provided for pursuing or not pursuing the need for specifying the use of only local native plant species in wetland replacement projects?

Since the three questions above cannot be answered and because of possible ecotypes among the natives, the Research Team believes it would be counterproductive to specify the use of local native plant materials for wetland replacement projects. One would not know if collection of the materials within an x-mile radius (+/- x-degrees latitude or longitude) from the wetland replacement site would ensure that the materials will be local native.

Additionally, the Research Team believes that specifying the use of only local native plant species in wetland replacement projects would:

- Vastly complicate the successful completion of these projects
- Substantially increase the costs of landscaping the projects
- Potentially endanger regional communities of native wetland plant species

> The Research Team recommends NOT specifying the use of local native plant species unless it is known to be a critical issue for the wetland replacement.

This is because there are few, if any, nurseries that can guarantee that their plant materials are local native to the wetland replacement site. Consequently, such a specification would require the "field collection" of native plant materials to use on wetland replacement projects. This potentially would endanger regional wetlands because it would require the denuding or impacting of one wetland to vegetate another. The Research Team regards this as counterproductive. Furthermore, there are no guidelines regarding acceptable geographical ranges for "field collection" in order to ensure that local native plant species are obtained.

If seed of local native plant species is specified to produce the required plant material, then the following questions arise regarding the feasibility of using seed:

- Where can one collect the seed to assure that it is native?
- When should it be collected?
- Is there a sufficient supply of local native plants to provide the required quantity of seed?
- How is the seed processed and stored?
- How are plants propagated from the seed?

All of the questions above regarding the use of seed are answerable. For some species the answers are known; for others, the questions will have to be researched. Provided that the seed is used for nursery plant propagation and not for site seeding, there generally will be a sufficient supply of local native plants to provide the needed seed. To assure that the seeds are local native, the collection site might be the wetland to be impacted and neighboring wetlands within a distance of 10 - 20 miles.

> **If local native plants are a critical element of the wetland replacement, specify the use of plants propagated from seeds of local native species.**

Often there is sufficient time between the award of a wetland replacement construction contract and the installation of the plant materials to contract-grow the necessary plant materials. If local native plant materials are specified, the best approach to assure that both the material is local native and that it is obtained by the required time is to:

- Specify that the plant materials must be contract-grown and provide the names of nurseries and horticulturists with the knowledge and capability of producing the materials
- Specify that the plant materials be derived from the seeds collected from local native plants
- Identify on the plans and specifications the location(s) where the seeds may be collected and indicate from whom and/or what agency or agencies permits will be required
- For trees and shrubs, specify plant heights that can reasonably be obtained in the growing time available (6-12 inches in one growing season and 12-20 inches in two growing seasons)
- For herbaceous plants, specify the use of seedlings, unless the growing time available allows the specification of other types of plant materials

USE OF LOCAL NATIVE PLANTS

If the use of local native plants is specified, the Research Team recommends (1) specifying that the materials be contract-grown from seed and (2) indicating possible growers. This will alert those bidding the contract to get prices for contract growing.

G.3 PLANT MATERIALS SPECIFICATIONS

G.3.1 General

Various types of plant materials may be used in wetland replacement projects. The basic types are summarized in Table G-10 together with their relative costs and relative survival rates.

Herbaceous wetland plant materials other than seed are generally either nursery-propagated under wetland conditions or field-collected from existing wetlands, and the materials are conditioned to wet cultivation. Consequently, transplanting these materials to wetland conditions is not a shock to the plants and the survival rates are usually high. The survival rates from transplanting growing bare-root materials are often lower than those of the other material types because new roots can be damaged from handling and, since the roots are generally clumped together upon transplanting, it is more difficult for the plant to achieve fast, uniform rooting in the soils. Transplanting growing bare-root and field-collected plugs during the middle or late growing season is not recommended because high stress to the plant materials in the process often leads to low survival rates.

REASONS FOR LOW SURVIVAL RATES

Low survival rates usually result from (1) transplanting growing bare-root herbaceous wetland plants during the middle or late growing season, (2) transplanting dormant bare-root woody wetland plants during the dormant season, and (3) transplanting field-collected trees and shrubs.

For many woody wetland plant species which are represented in forested wetlands, using bare-root plant material is inadvisable. Many of these woody species are facultative/facultative-wet and are grown in the ground in upland conditions by many nurseries throughout the U.S. Extracting or lifting bare-root woody plants from the ground shocks (stresses) the plants. Main roots often are cut and much of the fibrous root system often is lost during the process. Planting them into anaerobic or oxygen-deficient soils is an additional shock. Thus, the survival rates are generally low for woody bare-root materials. The survival rates for balled and bagged upland nursery-grown woody plant materials is generally not high for the same reasons, although the balling and bagging process is not as destructive to the root systems.

Do not let the low cost of bare-root woody plant materials induce their use. Specifying them could jeopardize successful initial plant establishment and require replanting with more suitable and more expensive materials.

Although some species of trees and shrubs transplant well from natural wetlands (the field), transplanted balled-and-bagged, tree-spaded, plugged-seedling, and bare-rooted plant materials often suffer high mortalities or grow poorly for several years because of the severe reduction in root biomass that takes place upon lifting them from the field and because of the loss of optimum growing conditions provided in the field. In addition, small-to-intermediate-sized understory plants are also stressed when transplanted to unshaded wetland replacement sites. For these reasons, field collection of trees and shrubs is discouraged.

Transplanting containerized plants and seedling plugs of woody species does not damage root systems and consequently their survival rates are relatively high.

Although there are instances of highly successful results from seeding (Section G.7), the seeding of most plant species has not been explored. Also, the commercial and field sources of seeds are extremely limited. Consequently, the following is true for most plant species:

TABLE G-10

TYPES OF PLANT MATERIALS, WHEN TO PLANT, RELATIVE COSTS, AND RELATIVE SURVIVAL RATES

Types	When to Plant	Relative Costs	Relative Survival Rates
WOODY			
Bare root	Dormant season	Low to intermediate	Low
Unrooted cutting	Dormant season	Low	Intermediate
Balled and burlapped	Any time of year	High	Low to intermediate
Container	Any time of year	High	High
Plug (seedling)	Any time of year	Low	High
Plug (collected)	Dormant/early growing season	Intermediate	Intermediate
Seed	Dormant season	Lowest	Low
HERBACEOUS			
Dormant propagule	Dormant season	Low	High
Growing bare-root	Early growing season	Intermediate	Intermediate
Container/fiber pot	Any time of year	High	High
Plug (seedling)	Any time of year	Low	High
Plug (collected)	Dormant/early growing season	High	High
Seed	Dormant season	Lowest	Low

- The seeding techniques and requirements are unknown.
- The hydrology requirements during seeding and after seeding for optimum seed germination and seedling emergence are unknown.
- The seed collection, processing, and storage requirements to ensure viable seeds are unknown.

If seeding is specified and unless it is known to the contrary, the time of seeding should be in the beginning of the growing season to provide a maximum time for the seedlings to mature before the dormant season.

Do not specify seeding any plant species unless it has been done successfully by others.

When seeds germinate, the seedlings have no record of what time of year or season it is. If photoperiods trigger flowering and the seedlings experience this "flowering" photoperiod shortly after seed germination, they may flower prematurely, thus completing their life cycle and probably dying. Many herbaceous plant species flower at the end of the growing season, another reason for not seeding during this time of year. Premature flowering is not an issue for tree and shrub seedlings, since such seedlings take many years to mature to a flowering stage.

G.3.2 NEED FOR SPECIAL CONDITIONING OF PLANT MATERIALS

G.3.2.1 Wet Culture

> **OBLIGATE SPECIES**
>
> Unless it is known to the contrary, only specify that "obligate" species be wet cultured.

There is no information regarding the need for wetland plant materials to be wet cultured by the nursery providing them. The wetland plant species that are classified as "obligate" (able to live under very restricted conditions) are most readily propagated under wet culture conditions. However, it is possible that many "obligate" species could be cultivated for a short term under normal nursery conditions. For this reason, it is recommended that "obligate" wetland species obtained from nurseries be wet cultured for a minimum of three months during the growing season to be acceptable for use in wetland replacement projects. No such requirement is recommended for "facultative" (able to live under a wide range of conditions) and "facultative wet" species. When specific information becomes available on this subject, these recommendations may be amended.

G.3.2.2 Water Salinity Conditioning

Most plant species found in salt and brackish marshes are salt tolerant and do not require salt in their propagation. Therefore, it is generally most economical and convenient to grow them under freshwater conditions. Salt-tolerant species that are grown under freshwater conditions can be transplanted to water salinities of up to 10 ppt (1%) without any signs of stress, but not above 10 ppt.

When species are to be planted in water salinities greater than 10 ppt during the growing season, it is recommended to condition them by having them grown for at least one month in water salinities that are within 5 ppt of the water salinity to which they will be planted. The water salinity should be gradually increased to the final value in increments of 5 to 7 ppt every several days by using sodium chloride. This recommendation does not apply to dormant plant materials transplanted during the dormant season: as they break dormancy, they will adapt to the local water salinity as the new roots and leaves emerge.

G.3.3 ACCEPTABLE APPEARANCE OF PLANT MATERIALS AND SAMPLE SPECIFICATIONS

It is important to specify in sufficient detail the acceptable appearances of the plant materials so that an inexperienced inspector can make a rapid determination of acceptability. The height of plant materials (e.g., 18-24 inches, 2-3 feet, etc.) often is specified as the criteria for acceptability. This is generally a suitable criterion **only** for woody plant species. For herbaceous species, the height criterion should be specified **only** to assure that the materials, when planted during the growing season, are tall enough to emerge above the specified water level (pool level or high tide level). Otherwise, specifying heights for herbaceous emergent plant materials is inappropriate. During dormancy, all dormant plant parts exist belowground, except for short dormant shoots: what is aboveground is the previous year's dead growth. During the growing season, the heights of plants increase until flowering, when plant growth terminates. This variability of height throughout the growing season makes height requirements unreasonable.

> **WHAT TO SPECIFY**
>
> - Only specify the heights of growing herbaceous plants to ensure their emergence from the water.
> - Do not specify the age of plant material.

Other criteria that should not be specified for dormant herbaceous plant parts are *size*, *thickness*, or *diameter* (of tubers, bulbs, corms, rhizomes, stolons, and suckers). Depending on the nutrient loads during their growth, these perennial plant parts might vary in size, thickness, or diameter by orders of magnitude and yet be acceptable for use.

The age of plants is generally of little relevance for specifications. A rhizome developed by a plant that is three months old often is indistinguishable from one developed by a plant that is one year old. Since new rhizomes are produced by the plants each year, there is no such thing as a two year old rhizome. Tubers develop at the end of each growing season and then produce plants that produce new tubers the next growing season. There is no such thing as a three-month old or a two-year old tuber. Bulbs and corms are perennial parts of plants. They are not seedlings. They may or may not increase in size with age; therefore, there is no practical purpose for specifying their age.

If for any reason it is undesirable to use seedlings as plant materials, state that "seedlings will not be accepted" or that "plant materials must be produced vegetatively (i.e., from perennial plant parts)." Generally in the nursery industry, tree and shrub seedlings that are older than two years are not considered seedlings, but instead are classified by height. Herbaceous plants are not considered seedlings after the first year.

There are exceptions to the above. For example, seedlings of the herbaceous species *Peltandra virginica*, *Spartina cynosuroides*, *Panicum virgatum*, and *Phragmites australis* develop slowly, taking two years to mature to a flowering state in the northeast. If it is important to use plant materials that will flower during the first growing season and it is known that seedlings of the species specified take two years to flower, then specify the use of 2-year-old seedlings or plant materials produced vegetatively. Examples C through L illustrate criteria for acceptability that might be specified for the types of plant materials cited in Table G-10. For all woody plant species, the **HEIGHT** specification should always apply.

EXAMPLES OF CRITERIA FOR ACCEPTABILITY THAT MIGHT BE PLACED IN THE SPECIFICATIONS

EXAMPLE C: Dormant Bare-root (Woody) Seedlings and Older Plants

These plant materials are listed in Table C-10 as having low to intermediate costs. To clarify this further, bare-root seedlings would have a relatively low cost, and older bare-root plants that include suckers and stolons would be of intermediate cost.

No more than twenty-five percent ($\leq$ 25%) of the root system (both primary and auxiliary/fibrous) shall show evidence of being cut (pruned) or stripped from the plant during the digging process. It is important that auxiliary/fibrous roots be present, since they facilitate initial absorption of water and nutrients when planted.

Plants shall be shipped by the nursery immediately after lifting from the field and planted immediately upon receipt by the wetland replacement landscape contractor. If shipping is delayed, the plants shall be stored at 1-4° Celsius with root masses protected by straw, peat moss, compost, or other suitable material and maintained moist until the time of shipping.

If the plants cannot be planted immediately after delivery to the wetland replacement site, they should be stored in the shade with their root masses protected from direct exposure to the wind by the use of straw, peat moss, compost, or other suitable materials and should be kept moist through periodic watering until the time of planting.

Plants not having an abundance of well-developed terminal buds on the leaders and branches shall be rejected.

The stems and branches of all plants shall be turgid, and the cambium colored light green to yellowish green; otherwise, the plant(s) will be rejected.

Any plants that are in leaf or that have leaflets (young leaves) shall be unacceptable.

Suckers shall contain a terminal shoot and be a minimum of four inches (4") in length (in order to ensure sufficient stored energy to support the new growth).

EXAMPLE D: Unrooted Cuttings

These are often referred to as "whips" or "poles." For willows and poplars, the cuttings should be taken from one-year-old twigs and be between 10 inches to 2 feet in length and 0.5 inches ± 0.1 inches in diameter. For cottonwoods, poles should be from 3- to 5-year trees and be 10 to 20 feet in length and 2 to 6 inches in diameter. For buttonbush, the cuttings should be taken from 1 year-old twigs and be between 10 to 15 inches in length and between 1/8 inch to 1/4 inch in diameter. No other species should be specified to be planted as unrooted cuttings.

EXAMPLES OF CRITERIA FOR ACCEPTABILITY THAT MIGHT BE PLACED IN THE SPECIFICATIONS (continued)

EXAMPLE D: Unrooted Cutting (continued)

Unrooted cuttings shall be harvested and planted during the dormant season. After harvesting, the cuttings shall be wrapped in plastic and refrigerated at just above freezing until delivery to the job site. They shall be delivered to the job site with their bottoms (cut point) in pails of water (or other suitable containers filled with water).

Cuttings that are brittle or not turgid shall be rejected.

EXAMPLE E: Balled and Bagged (Woody Plants)

The size of the earthen ball shall be at least as large as specified in the *American Standard for Nursery Stock* (American Association of Nurseryman, Inc. 1980). If the plants are to be planted in soils that will be saturated most of the growing season, the earthen ball shall have a surface diameter that is 50% to 65% of the diameter of the un-pruned drip-line and a depth that is at least 8" per 5' of tree/shrub height.

If the plants are not immediately planted after delivery to the job site, they shall be stored in the shade and their root balls kept moist through periodic watering until the time of planting.

If growing, the plants shall appear healthy, with no leaf spots, leaf damage, leaf discolorations, chlorosis, leaf wilting or curling, or evidence of insects on the leaves.

EXAMPLE F: Container (Woody and Herbaceous Plants)

The soil/root masses shall be saturated upon delivery to the job site. Any dry and light weight plants shall be rejected. If not planted immediately after delivery to the job site, the plants shall be stored out of direct exposure to the sun and wind and their root masses kept moist through periodic watering until the time of planting.

Upon the removal of the plants from the containers, the soil/root masses shall be the size of the specified container size. If the soil/root masses are substantially smaller than that and loose soil is found on the bottom of the containers, the plants shall be rejected since they have not been grown sufficiently long in the containers to root into the soils there.

If growing, the plants shall appear healthy, with no leaf spots, leaf damage, leaf discolorations, chlorosis, leaf wilting or curling, or evidence of insects on the leaves.

For trees and shrubs, should spiraling primary woody roots exist on the outside of the soil/root mass, upon removing the plants from the containers, the landscape contractor shall be instructed either to cut these roots or separate and spread them out from the soil/root masses prior to planting.

The container size shall be at least as large as indicated in the specifications or shown in the plant tables/lists. Plants shall not be rejected if supplied in containers larger than specified.

EXAMPLES OF CRITERIA FOR ACCEPTABILITY THAT MIGHT BE PLACED IN THE SPECIFICATIONS (continued)

EXAMPLE G: Fiber or Peat Pot (Herbaceous Plants)

If not planted immediately after being delivered to the job site, the plants shall be stored out of direct exposure to the sun and wind and their pots and associated root masses kept moist through periodic watering until the time of planting.

The plants shall be well rooted through the sides and bottoms of the pots and firmly contained therein.

Should the plants be removed from the pots by holding them by their tops and gently pulling on the pots, the plants shall be rejected.

If growing, the plants shall appear healthy with no leaf spots, leaf damage, leaf discolorations, chlorosis, leaf wilting or curling, or evidence of insects on the leaves.

The pot size shall be at least as large as indicated in the specifications or shown in the plant tables/lists. Plants shall not be rejected if supplied in pots larger than specified.

The number of plants or stems (culms) per pot as specified in the plant tables/lists shall be present at the minimum, and on the average, or the plants shall be rejected.

EXAMPLE H: Dormant Propagule (Herbaceous Plants)

These may be tubers, bulbs, corms, rhizomes (herbaceous), or stolons. They are the most difficult to specify for understanding by an inexperienced inspector.

If not planted immediately after being delivered to the job site, the dormant propagules shall be stored out of direct exposure to the sun and wind; they shall be protected by covering with straw, peat moss, compost, or other suitable materials; and they shall be kept moist through periodic watering until the time of planting.

The bodies and shoots associated with the propagules shall have turgor or be rigid to the touch. If the bodies and/or shoots associated with the propagules are soft or mushy or appear rotten or decomposed, the plant materials shall be rejected. Rhizome (stolon) sections shall provide a minimum of two shoots per section. Or: Rhizome (stolon) sections containing at least a terminal shoot shall be a minimum of four inches (4") in length (in order to ensure sufficient stored energy to support the new growth). Rhizome sections containing shoots that are soft or mushy or otherwise appear rotten shall not be accepted.

EXAMPLES OF CRITERIA FOR ACCEPTABILITY THAT MIGHT BE PLACED IN THE SPECIFICATIONS (continued)

EXAMPLE I: Growing Bare Root Plant (Herbaceous Plants)

The plants shall contain new roots that are clean and white in coloration.

If not planted immediately after delivery to the job site, the plants shall be stored out of direct exposure to the sun and wind, and the new roots shall be protected by the use of straw, peat moss, compost, or other suitable materials and shall be kept moist through periodic watering until the time of planting.

The plants shall appear healthy with no leaf spots, leaf damage, leaf discolorations, chlorosis, leaf wilting or curling, or evidence of insects on the leaves.

EXAMPLE J: Plug (Herbaceous Plants, Woody Seedlings, or Rooted Cuttings)

If not planted immediately after delivery to the job site, the plugs in their growing units shall be stored out of direct exposure to the sun and wind and maintained moist through periodic watering until the time of planting. If the plugs are not contained in their growing units upon delivery and will not be planted immediately, they should be treated as above and their root masses shall be protected by straw or other suitable materials and kept moist through periodic watering until the time of planting.

Plugs shall have solid soil/root masses with the soil in place. Roots shall appear clean and white in coloration.

If growing, the plants shall appear healthy with no leaf spots, leaf damage, leaf discolorations, chlorosis, leaf wilting or curling, or evidence of insects on the leaves.

If dormant (herbaceous), new healthy shoots shall be apparent. Plugs containing shoots that are soft or mushy or otherwise appear rotten shall not be accepted.

If dormant (woody), stems shall be pliable and exhibit light green to yellowish green cambium. Plugs containing brittle stems and having unhealthy cambium shall not be accepted.

EXAMPLE K: Plugs (Collected; Herbaceous and Woody Plants)

Plugs (herbaceous) shall be a minimum of five inches (5") square or in diameter and three inches (3") in thickness.

Plugs (woody seedlings) shall have widths that are at least to the limb lines of the seedlings and have depths that are at least one-fourth the heights of the seedlings.

EXAMPLES OF CRITERIA FOR ACCEPTABILITY THAT MIGHT BE PLACED IN THE SPECIFICATIONS (Continued)

EXAMPLE K: Plugs (Collected; Herbaceous and Woody Plants) (continued)

If not planted immediately after delivery to the job site, the plugs shall be stored out of direct exposure to the sun and wind and shall be kept moist through periodic watering until the time of planting.

If growing, the plants shall appear healthy with no leaf spots, leaf damage, leaf discolorations, chlorosis, leaf wilting or curling, or evidence of insects on the leaves.

If dormant (herbaceous), new healthy shoots shall be apparent emerging from the surface of the plugs. Plugs containing shoots that are soft or mushy or otherwise appear rotten shall not be accepted.

If dormant (woody), the stems and branches shall be turgid and the cambium shall have a light green to yellowish green coloration. Any plants with brittle stems and branches shall not be accepted.

EXAMPLE L: Seed

Seed shall be delivered in containers (bottles, jars, paper/cloth bags/sacks) having labels that report the origin of the seed, the purity of the seed, the germination percentage, and date of germination testing of the seed.

G.4 FIELD COLLECTION OF PLANT MATERIALS

G.4.1 WHERE TO COLLECT

Wetlands are either privately or publicly owned, and if collection from the wetland(s) that will be impacted is inappropriate (other plant species are being specified, etc.) or not feasible (timing problems, etc.), then arrangements will have to be made to collect from other natural wetlands. These arrangements include identifying locations for collections; obtaining any necessary authorizations, permits, or permissions for collections; and, finally, scheduling the collections.

It may not be a simple matter to identify suitable locations for collections. State wetland maps or peoples' recollections may be of little help unless they have been recently updated. Vegetative compositions are constantly changing due to:

- Animal "eatouts"
- Hydrological changes caused by animals (e.g., beavers)
- Natural processes (eg., sea-level changes)
- Meteorological events (e.g., five-year drought)
- Mechanical failures (e.g., tide-gate sticking or culvert clogging)

If seeds are being collected, seed production and quality may vary yearly due to meteorological factors, disease, and insect infestations. The only reliable way to identify suitable locations for collections is through on-site verifications.

The preferred locations to collect plant materials are:

- The wetland(s) to be impacted
- Another donor wetland that is permitted to be destroyed
- Roadside ditches

UNAVAILABLE STOCK

It is strongly recommended to contract-produce plant materials for wetland replacements if the species, types, and/or quantities are unavailable in existing nurseries (Appendix H.5). If this is not done, the only source for the plant materials will be the field.

Wetlands are increasingly being constructed nationwide for wastewater treatment. Many of these wetlands are designed for underground flow and have to be cleaned of plant materials periodically to maintain this flow. If these wetlands contain the desired plant species, they may be an economical source for perennial plant parts and for seed.

If the above field sources prove unproductive, other wetland sources will have to be explored. From ecological and economical perspectives, wetlands that are monotypic in the desired plant species are preferred for collection over wetlands with a high species diversity. Normally, collecting the desired plant materials from such monotypic wetlands will be most economical because it will be accomplished quickly and efficiently. The process of collecting plant parts will lead to open areas in the wetland. This will provide some diversity until such time that these open areas fill in with the surrounding plants.

NATIVE PLANTS COLLECTION

It is expected that it will be increasingly difficult to obtain permits for the field collection of native plants.

If field collection of plant materials is likely or will be necessary, the Wetland Replacement Construction Plans and Specifications must provide the information regarding WHERE, WHEN, and HOW to collect (Chapter 5). These Plans and Specifications also must indicate what authorizations, permits, or permissions are necessary to engage in the collection or indicate that whatever will be necessary will be provided to the landscape contractor by the project sponsor. It cannot be presumed that the landscape contractor will know this information.

G.4.2 WHEN TO COLLECT

The proper time to collect depends on the types of plant materials that are specified and when they must be planted to the wetland replacement site.

G.4.2.1 Seed

The time for seed collection is critical because if the "seed collection window" is missed, an entire year is lost. There are three types of plants from which it is difficult to collect seed:

- One type produces seeds that shatter and fall to the ground soon after ripening. Many species in the grass family fall into this category. For this plant type, one storm or windy day soon after seed ripening can cause the loss of seed.

- A second type of plant flowers and produces seed during much of the growing season so that there is no optimum time for seed collection. An example of this type is *Pontederia cordata*.

- A third type of plant produces seed that is of high wildlife value and one must compete with local fauna to collect the seed. (See Table G-9 in Section G.1 for candidates for this type of plant.)

SEED COLLECTION

The seed collection "window" often will be one to two weeks, during which competition with storms and wildlife may prevent high yields, and a whole year could be lost.

As the optimum time for seed collection of any species often will vary depending on location within a state or region, this information is best obtained through consultation with local wetland scientists and botanists.

G.4.2.2 Herbaceous Plant Material

This includes dormant propagules, growing bare root plants, and plugs. The optimum time to collect these plant materials for the specified plant species is just before they are to be planted in the wetland replacement site. Doing this eliminates any storage and maintenance requirements. Consequently, the collection and planting processes should be coordinated. Specifications for these plant materials are provided in Section G.3 (Plant Materials Specifications).

WHEN TO PLANT

Avoid the cost of storing collected materials: specify that they be planted directly after collection.

G.4.2.3 Woody Plant Material

This includes trees and shrubs. Although some species transplant well, transplanted balled and bagged, tree-spaded, and bare-root trees and shrubs often suffer high mortalities or grow poorly for several years because of the severe reduction in root biomass upon lifting from the field and because of the loss of optimum growing conditions provided in the field. Also, the transplanting expense often is prohibitively high. For these reasons, field collection of trees and shrubs is discouraged. However, if trees and shrubs are collected, they should be collected in the dormant condition.

G.4.3 HOW TO COLLECT

G.4.3.1 Seed

Mechanical devices have been developed for the field collection of prairie plant seeds, and these may be applicable for seed collection under certain wetland conditions. However, seed collection by hand using hedge cutters, shears, sickle, or other cutting tools will probably work best under most wetland conditions.

G.4.3.2 Herbaceous Plant Material

> **HAND & SHOVEL COLLECTIONS**
>
> Specify the use of hand and shovel for collections from natural wetlands.

This includes dormant propagules, growing bare-root plants, and plugs. Collection of these plant materials from the wetland(s) that will be impacted might be assisted, depending upon ground conditions, by the use of a backhoe, excavator, or other mechanical means; however, collection of these plant materials from natural wetlands generally should be accomplished by hand and shovel. The use of excavators and other mechanical devices for collection in natural wetlands generally will be too destructive. The use of a water pump might assist in cleaning dormant propagules so that they can be properly selected, processed, and inspected. A water pump also might be used to wash some of the sediments off growing bare-root plants, making them easier to handle (ship and plant). Plugs generally do not need to be washed.

During the collection process, it is strongly advised not to denude large areas of wetlands but to collect the plant materials in a "checkerboard" pattern (i.e., a "checkerboard" grid of about 5 sq ft) so that remaining plants will always be nearby to fill in the barren areas within a year or two. Planting requirements such as the method described here might be placed in the Construction Plans and Specifications.

If collections are being made from peat wetlands, as opposed to wetlands with less structured soils, the holes created by taking plugs or the removal of other plant materials often will fill in with water rather than with sediments. In such instances, plants will not return to these "collection holes" unless they are filled with sediment. If the wetland conditions are such that these "collection holes" will result, it may be important to specify in the Construction Plans and Specifications that they be filled with mineral sediments following the collection process. Otherwise, these "collection holes" will persist and negatively impact the wetland, particularly for projects where large numbers of plant materials are collected.

If the wetland soils are such that the "collection holes" fill in with sediment, vegetation will usually fill in these bare areas within several years, provided the "checkerboard" grid is not too large and provided the surrounding vegetation propagates by rhizomes, stolons, or tubers. If the perennial parts of the surrounding vegetation are bulbs or corms, the surrounding vegetation will only fill in through seeding, or other species will volunteer the bare areas. The spreading rates of plant species that are given in Table G-8 in Section G.1 will provide some indication of the time it will take for surrounding vegetation to fill in the "collection hole" bare areas, depending on the size of the "checkerboard" grid.

COLLECTING HOLES

Collecting plants from peat wetlands will result in holes that fill with water and not soils. If this is not desirable, specify that the holes be filled with a sandy loam.

G.4.3.3 Woody Plant Material

Depending on ground conditions, the use of a backhoe, excavator, or tree spade will greatly facilitate the lifting of the larger plants for transplanting. Plugs of small seedlings/saplings (12 - 24 inches), with soil intact, can often be extracted by hand and shovel.

G.4.4 WHAT TO DO WITH THE COLLECTED MATERIALS

G.4.4.1 Seed

As opposed to other collected plant materials, collected seed should not be used for seeding a wetland replacement area directly after collection. Before seeding, the seed purity and germination percentage must be determined, as seeding specifications should indicate seeding rates using pure live seed (pls). Consequently, the collected seed must be cleaned, processed, analyzed for purity, stored, and germination tested before being used. Section G.7, Plant Seeding, provides some of this information for several species.

As stated above, it is recommended that a local wetland scientist be consulted concerning when to collect seed in order to identify the proper specifications for processing and storing it.

G.4.4.2 Herbaceous and Woody Plant Material

This includes dormant propagules, growing and dormant bare root plants, plugs, balled and bagged plants, and tree-spaded plants. As indicated in Sections G.4.2.2 and G.4.2.3 above, these materials generally will be collected just before planting. Consequently, they will be delivered to the wetland replacement site shortly after collection. It is important that these plant materials be delivered in conditions that are compatible with the Construction Plans and Specifications. Section G.3, Plant Materials Specifications, provides some general specifications for these plant materials.

G.5 PLANNING FOR VEGETATION NEEDS

Although an increasing number of new nurseries are listing wetland plant species every year, the total number of such nurseries is extremely low and the total number of such nurseries (wholesale) that carry a significant inventory of a large number of plant species is minuscule. Consequently, the required quantities of plant materials for species specified for wetland replacement projects often are unavailable commercially.

> **COMMERCIALLY AVAILABLE PLANTS**
>
> Wetland replacement designers must make an effort to specify only plant materials that are commercially available.

In addition to this problem, the market demand is far from becoming stabilized for species, plant material type, and total quantity. No nursery will grow tens of thousands of cattails in quart containers if there is no assurance that even one quart will be sold the following year. One reason for market instability is that persons designing wetland replacement projects are NOT taking the time and effort to find out which nurseries are carrying what species and what types of wetland plant materials. Instead, they are writing specifications without checking to see what is really available.

When the quantities of plant materials for species specified for wetland replacement projects are unavailable commercially, the only sources for these plant materials are natural wetlands. Extracting large quantities (thousand to tens of thousands) of plugs or other planting units from natural wetlands can have major negative impacts, even when done by experienced persons (Section G.4, Field Collection of Plant Material). From a practical standpoint, the wetland replacement process is unproductive if it leads to significant impacts to natural wetlands in addition to those inflicted by the project.

> **Wetland replacement makes no sense if the process leads to negative impacts on natural wetlands.**

Specifically, most highway and other major development projects require long lead times before they are constructed. Thus, ample time is available (i.e., greater than one calendar year) to obtain the required plant materials for the wetland replacement. Following are three examples of planning for vegetation needs.

Planning for plant material needs for wetland replacement projects is strongly recommended, especially when the required quantities are in the hundreds for woody materials and in the thousands for herbaceous materials. Such planning should involve contracting out—by the project sponsors or by the prime contractors—the production of the required plants with ample time to produce high-quality materials.

EXAMPLES OF PLANNING FOR VEGETATION NEEDS

EXAMPLE M: Project sponsors notify regional and remote nurseries of their forthcoming plant material needs and timetables, in the hopes that one or more of them will gamble and produce some or all of the plant materials and then notify the general contractor on their availability following the award of the contract. This is not the recommended planning approach, because it puts too much at risk for the nurseries. Delays are standard with highway projects, and plant materials may have to be held over and maintained for unknown periods of time. This would lead to price increases for the nursery plant materials so that the new prices would be uncompetitive with those for plant materials extracted from natural wetlands.

EXAMPLE N: Specify in the highway project contract that the general contractor is responsible for subcontracting the production of the required plant materials with sufficient lead time (generally one year or longer) so that it becomes unnecessary for these materials to be extracted from natural wetlands. This is preferred over Example M, but not over Example O because landscaping requirements in highway projects are often low cost and such specifications may be overlooked or considered insignificant by prime contractors bidding the jobs.

EXAMPLE O: Prior to, concurrent with, or subsequent to, letting the highway project contract -with sufficient time to produce the necessary plant materials—the project sponsors go out for bid from regional and remote nurseries for growing contracts or seed production contracts for the plant materials required by their wetland replacement projects. This is the preferred process, although, for various reasons, not all project sponsors are able to pursue it. Another option is to hire a landscape contractor to carry out the mitigation. The contractor can be hired in combination with a separate contract for growing material, or a landscape contractor could handle the contract growing. This approach requires coordination with the wetland construction contractor to ensure appropriate sequencing of work.

G.6 PLANTING

G.6.1 GENERAL

Planting dormant or growing plants and plant propagules is the most reliable approach to achieving successful vegetation establishment of the specified plant species. Seeding and topsoiling with wetland soils/seed banks are economically attractive approaches, but current techniques are sufficiently underdeveloped, producing unreliable, unpredictable, and often unsuccessful results.

Using wetland replacement projects to experiment with new techniques that might improve the process and make it less costly should be encouraged, but not at the expense of overall success of the project. Consequently, experimental (UNCERTAIN) work should be specified for and confined to a small percentage (e.g., 5%) of the overall project, so that this work, if unsuccessful, does not jeopardize the success of the entire project.

Planting herbaceous and woody wetland plants is no different than planting other types of plants.

Although some sample planting specifications are provided here, generally planting specifications should reflect those of the standard landscaping industry.

Planting in the dry (with most water drained from the site) should always be specified, if at all possible: it is more likely to be done properly, and planting costs will be reduced by as much as a factor of 10, particularly if the water is deeper than two feet and scuba divers have to be employed for the installation. Costs for planting in even six inches of water may be double that for planting in the dry. The greatest difficulty in planting under water is to get the planting crew to take its time and ensure that the plants and fertilizer are firmly installed in the sediments so they do not float out. Often the working conditions are unpleasant and the planting crew wants to get the work done as quickly as possible, becoming careless in the process.

If planting under water is required, highlight in the planting specifications that the landscape contractor shall be required to re-install any plants that are found floating or washed along shore.

PLANTING SPECIFICATIONS

Although it is the most expensive method, give first priority to planting rather than seeding or the spreading of wetland soils. Keep experimental work to a minimum. It will always cost more to correct work that fails.

Whenever possible, plant in the dry. It is the least expensive and most reliable means of correctly installing plants.

G.6.2 PLANTING DENSITIES

Planting densities will greatly influence the planting costs and should be arrived at objectively, not arbitrarily copied from the specifications of another wetland replacement project. There should be reasons, other than cost, for low density plantings.

The substrate compaction will greatly affect herbaceous and woody plant survival as well as development and the spread rate by herbaceous and sometimes woody (spread by suckers) plants. Substrate compaction should not be a determining factor of planting density. Site construction plans and specifications should always state that the substrates to be planted are to be deconsolidated by plowing, discing, rototilling, or ripping. Substrates for herbaceous plants should be deconsolidated to depths of 4-6 inches. Substrates for trees and shrubs taller than 1-year-old seedlings may have to be deconsolidated to depths of between 12-18 inches.

DECONSOLIDATING SEDIMENTS

Sediments always should be deconsolidated following site construction and prior to planting.

G.6.2.1 Herbaceous Species

Rapid vegetation coverage may be critical in various instances. The following examples illustrate such cases.

EXAMPLES OF THE NEED TO ACHIEVE RAPID VEGETATIVE COVER (continued)

EXAMPLE P: The wetland replacement site may be surrounded by an abundance of one or more invasive plant species. The longer open ground is available, the greater the likelihood that this species will invade the wetland replacement site and become a significant management problem during the maintenance phase of the project and later.

EXAMPLE Q: There may be an abundance of wildlife known to be in the area that will be particularly damaging to vegetation that remains clumped, as opposed to uniformly covering the site.

EXAMPLE R: Site grades at certain locations may demand rapid sediment stabilization for erosion control.

EXAMPLE S: A design function of the wetland replacement may be such (e.g., water quality improvement or cover for wildlife nesting) that rapid vegetation coverage is necessary.

In other instances, rapid vegetation coverage may not be important to achieving the wetland replacement objectives.

AN EXAMPLE WHERE RAPID VEGETATION COVERAGE IS UNNECESSARY

EXAMPLE T: Open areas throughout the replacement site may be desirable for certain lengths of time to recruit other desirable species in wetlands nearby or that are hydrologically connected to the replacement site.

Table G-8, Special Characteristics (Section G.1), describes these rates of spread for herbaceous and woody plant species in unconsolidated sediments:

- Rapid = > 1 foot per year
- Moderate = 0.5 ± 0.1 foot per year
- Slow = < 0.2 foot per year

Table G-11 provides recommended planting densities for achieving uniform aerial coverage for slow spreading plants and uniform ground coverage for moderately and rapidly spreading plants in one, two, and three growing seasons.

Table G-11 can be used to estimate the desired planting density (on-center planting) after determining the desired time for achieving uniform vegetation coverage. Table G-13 or Equation 1 then can be used to calculate the required number of planting units for the project.

From Table G-12 or Equation 1, below, planting a given area 6 inches on center requires 144 times the number of plants than would be needed to plant the same area 6 feet on center. Careful consideration, therefore, should be given to proper planting densities to calculate the total plant material required.

TABLE G-11

RECOMMENDED PLANTING DENSITIES FOR ACHIEVING UNIFORM AERIAL AND GROUND HERBACEOUS COVERAGE

RATE OF SPREAD	UNIFORM AERIAL COVERAGE			UNIFORM GROUND COVERAGE		
	1 Year	2 Year	3 Year	1 Year	2 Year	3 Year
Rapid				2 ft OC*	4 ft OC	6 ft OC
Moderate				1 ft OC	2 ft OC	3 ft OC
Slow	0.5 ft OC	1 ft OC	1.5 ft OC			

*On-center planting

G.6.2.2 Woody Species

In planting forested or scrub shrub wetlands replacement sites, density considerations are different from those for planting herbaceous wetlands. The density of tree and shrub planting will not affect the recruitment of invasive plant species, incursion by problem animals, soil stabilization, or the short-term functioning of the replacement wetland.

Cover crops should be specified and planted/seeded to provide sediment stabilization and erosion control, food and cover for wildlife, nutrient cycling, and other advantages. Cover crops must not consist of aggressive rhizomatous turf forming plants or other species that would be highly competitive for nutrients and moisture.

Target tree and shrub densities should not come from a single "reference wetland" because of the differences between wetlands. Rather, preferred species of trees and shrubs and herbaceous understory species, together with target-relative densities of these species, should be obtained from a number of regional "reference wetlands" of the same type being replaced. In determining the densities of the preferred species to plant over their target densities, consideration should be given to losses due to herbivory, drought, and natural thinning, as well as gains arising from possible natural regeneration.

Although the numbers will vary with "reference wetlands" for different wetland types, the recommended overall density of tree planting for forested wetlands is approximately nine feet on center, with herbaceous and shrub understory plants planted in groups 6 feet on center, with a total of approximately 1,210 plants per acre. For scrub-shrub wetlands, the recommended overall density of shrub plantings is approximately seven feet on center, with scattered herbaceous understory plants totalling approximately 890 per acre.

COVER CROPS

Plant or seed cover crops of nonaggressive and noncompetitive bunch grasses in wooded wetlands (Section J.7.3).

TABLE G-12

CALCULATION OF THE REQUIRED NUMBER OF PLANTING UNITS

ON-CENTER DISTANCE BETWEEN PLANTING UNITS	NUMBER OF PLANTING UNITS PER SQ FT (EQUATION 1)	PER ACRE (EQUATION 2)
0.5 ft	4	174,240
1.0 ft	1	43,560
1.5 ft	0.444	19,360
2.0 ft	0.250	10,890
3.0 ft	0.111	4,840
4.0 ft	0.063	2,720
5.0 ft	0.040	1,740
6.0 ft	0.028	1,210
7.0 ft	0.020	890
8.0 ft	0.016	680
9.0 ft	0.012	540

- **Equation 1:**

Number of Planting Units (PU) $= \frac{\text{(area in sq ft)(per 1 sq ft)}}{\text{(On-center spacing in ft)}^2} = \frac{1\ ft^2}{(0.5\ ft)^2} = \frac{1\ ft^2}{0.25\ ft^2} = 4$ PU

- **Equation 2:**

Number of Planting Units $= \frac{\text{(area in sq ft) (per acre)}}{\text{(On-center spacing in ft)}^2} = \frac{43{,}560\ ft^2}{(0.5\ ft)^2} = \frac{43{,}560\ ft^2}{0.25\ ft^2} = 174{,}240$ PU

G.6.3 FERTILIZER AND SOIL AMENDMENT REQUIREMENTS

Because most wetland replacement sites will consist of uplands that are required to be excavated to lower wetland grades, the soils at final grades almost always will consist of infertile mineral subsoils. Consequently, at least one fertilization at the time of planting is required. Depending on the appearance of the plants during the maintenance and monitoring programs, additional fertilizations may be warranted.

For the planting of herbaceous wetlands, soil amendments generally are not recommended. The annual underground biomass produced by many emergent herbaceous plants is 50% to 60% of their total annual biomass. Consequently, organics are being naturally put into the soils so rapidly that any augmentation through a soil amendment is unnecessary. Because trees and shrubs do not provide organic underground production similar to herbaceous plants, organic soil amendments to planting holes or beds generally are found to be advantageous when planting woody vegetation. For both herbaceous and woody wetland planting, it is unnecessary to over-excavate and then backfill to grade with conventional topsoils, unless the soils at and below the final grade are unsuitable for the support of vegetation (Appendix E).

REFERENCE WETLANDS

Reference wetlands should be used only to identify target species and densities for design and establishing goals for out-of-kind replacement wetlands.

G.6.3.1 Herbaceous Species

Except when seeding (Section G.7), a slow-release fertilizer always should be used. OSMOCOTE® is the one commercial fertilizer found to release nutrients under saturated soil conditions approximately over the time frame the manufacturer specifies. It is available in the following three useful time-frame releases:

- For summer planting, use 19-6-12, three- to four-month release.
- For spring planting, use 18-6-12, eight- to nine-month release.
- For winter/fall planting, use 18-5-11, twelve- to fourteen-month release.

FERTILIZERS & TOPSOILS

- Always fertilize at the time of planting. If done properly, nutrients will not migrate from the planting site.
- The use of topsoils normally is not required, and soil amendments are recommended only for trees and shrubs.

OSMOCOTE is pelletized and, therefore, difficult to use when planting under water. Although the pellets are denser than water and sink, the water normally is so turbid from sediment disturbance during planting that the planting holes cannot be seen. The OSMOCOTE can be bagged in burlap; however, this adds to the cost of planting. Consequently, if planting under water is possible or required, the use of AGRIFORM 20-10-5 two-year release, 10-gram planting tablets should be specified. These fertilizer tablets can be placed simultaneously in the planting hole with the plant materials.

Table G-13 provides the recommended quantities of OSMOCOTE (for planting in the dry) and AGRIFORM (for planting under water) fertilizers for the indicated herbaceous plant materials.

Equation 2 may be used to calculate the total number of pounds of OSMOCOTE required for a planting.

- **Equation 2:**

$$\frac{\text{(number of planting units) (grams OSMOCOTE/plant)}}{\text{(454 grams per pound)}} = \text{pounds OSMOCOTE required for planting}$$

G.6.3.2 Woody Plants

Either 12- to 14-month release OSMOCOTE 18-5-11 or AGRIFORM 20-10-5, 2-year release, 10-gram tablet fertilizer is recommended. For AGRIFORM, use at the manufacturer's recommended rate. For OSMOCOTE use:

AMOUNT PER PLANT (fluid oz given for easier measurement in field)	FOR SHRUBS OR TREES
30 grams (1 oz)	1 quart container
90 grams (3 oz)	1 gallon container
30 additional grams (1 oz)	for each additional gallon
15 grams (0.5 oz)	seedling plug

TABLE G-13

RECOMMENDED QUANTITIES OF FERTILIZER FOR VARIOUS HERBACEOUS PLANT MATERIALS

Type of Plant Material	Quantity of OSMOCOTE (fluid oz provided for field measuring)	Quantity of AGRIFORM 20-10-5 10 g tablets
Dormant propagule	15 grams (0.5 oz)	1 tablet
Growing bare-root	15 grams (0.5 oz)	1 tablet
Container/fiber pot	30 grams (1 oz)	3 tablets
Plug (seedling)	15 grams (0.5 oz)	1 tablet
Plug (collection)	30 grams (1 oz)	3 tablets

The recommended soil amendment when planting trees and shrubs is leaf or pine bark compost. Equal parts of soil and pine bark or leaf compost together with the fertilizer should be used to backfill the plant in the planting hole. The leftover soils from creating the planting holes should be raked about the plants so as not to alter the surrounding grades significantly.

Assuming that the planting hole is approximately twice the size of the container, Equation 3 may be used to estimate the required amount of compost.

- **Equation 3:**

(Number of plants) (Container size in gal.) (0.005 cu. yds. / gal.) = Cubic Yards of Compost

For 5,000 plants in quart containers:

(5,000) (1 qt.) (1 gal. / 4 qt.) (0.005 cu. yds. / gal.) = 6.25 cu. yds. of compost

For 1,000 plants in gallon containers:

(1,000) (1 gal.) (0.005 cu. yds. / gal.) = 5 cu. yds. of compost

G.6.4 CONSIDERATIONS FOR PLANTING SPECIFICATIONS

A frequently observed error on wetland replacement plans and specifications is showing or requiring that bowls be developed around the planting holes with leftover soils after planting the trees and shrubs. Mulching throughout the bowls also is frequently specified. Such soil mounding often withholds water from the plant, the opposite of its purpose, since in many forested and scrub-shrub wetlands, water sheet-flows over the substrate surface. At high water levels, any mulch would be washed away. Also, in more permanently flooded wetlands, such bowls will serve no function. It is recommended that surplus soils be raked about the plants so as not to restrict water flow or to alter the elevations significantly.

In situations where irrigation is used, such bowls would not be beneficial. Should plants have to be watered by hand during periods of drought, the absence of bowls would require watering at slower flow rates than with bowls.

BOWLS & MULCH

- Do not build bowls around planting holes with excess soils. Bowls divert water from the plants during overland flow.

- Do not mulch plants, since mulch will wash or float away.

Considerations that might be included in the planting specifications are given below.

G.6.4.1 Stabilizing Woody Vegetation

If the wetland replacement site will have saturated soils year-round, and if it is in a frigid area where the depths of ponded water during periods of freezing will be less than several inches, then it is recommended that trees and shrubs of more than 4 feet in height be staked using standard landscape specifications. Wetland trees and shrubs root poorly and at shallow depths under anaerobic substrate conditions. For periods up to several years or until the surface roots become well developed, plants may be blown over.

If trees and/or shrubs are to be planted in frigid sites that are expected to have more than several inches of standing water during periods of freezing, then all plants should be wired to metal anchors, regardless of size. Standard landscape specifications should be used, except that anchors should be specified to be sufficiently deep so they will not pull out if the plants are lifted by ice. Also, under these site conditions:

- Plants should be planted in the beginning of the growing season to provide maximum time for rooting and to become stabilized within the soils before freezing.

- The plants should not be fertilized or should be fertilized only with a zero or low nitrogen-based slow-release fertilizer to promote root development.

G.6.4.2 Cutting Herbaceous Vegetation

If emergent herbaceous plants are specified to be planted at the end of the growing season in frigid sites where the water may rise above the ground surface during freezes, it should be specified that the tops of the plant materials be cut to within 2 inches of the ground surface so that rising ice will not pull the plants out of the ground. If planting is completed at the beginning of or during the growing season, cutting the plants back at the end of the growing season generally will not be necessary because the plants should be well rooted by this time.

G.6.4.3 Planting Methods

Plant roots do not develop through pockets of air. When roots reach air, they stop developing and become "air pruned." Consequently, in seasonally or temporarily flooded wetlands where air often occupies voids in the soil, specifications should state that plants from flat-bottomed containers must not be planted in V-shaped dibbled or spaded holes. Otherwise, air pockets at the bottom of the holes may lead to plant mortality.

Specifications should state that trees and shrubs should *not* be pruned prior to or following planting. Wetland replacement projects are not ornamental gardens, and dead branches are in no way detrimental to the success of the project. They provide important habitat for insects which, in turn, may be a food source for woodpeckers and other wildlife.

PLANTING TIPS

- Plant root mass must have good contact with the soil. Air pockets in the planting hole will lead to root pruning or plant mortality.

- Plant hardwoods straight. Leaning trees may die.

It is important to specify, particularly for hardwoods, that all trees be planted erect. Any trees showing a lean of greater than 10 degrees from perpendicular must be straightened or replanted. Leaning trees often will sprout a new leader from close to ground level or will die.

Specify that unrooted cuttings (whips) of buttonbush, willows, and poplars be planted vertically with buds up and no more than one half of the total length of the cutting above ground. The use of rooting hormones generally does not increase survival for these plant species.

G.7 SEEDING

G.7.1 GENERAL

Seeding is normally the least expensive way to establish vegetation. Consequently, there is great interest in its application to wetland replacement projects.

Unfortunately, there is extremely little information in the literature from wetland scientists or from wetland restoration practitioners regarding which wetland plant species can be successfully seeded. For species that can be successfully seeded, information regarding technique(s), limitations, and special requirements for successful seeding must be understood and incorporated into the plans and specifications.

Seeding wetland species under wetland conditions is not straightforward, even if the acquisition of viable seeds is. Often, seeding is specified for wetland replacement projects, but the source(s) of seeds, techniques, and special requirements generally are not. Seeding techniques specified are often erroneous, as the following examples illustrate.

EXAMPLES OF ERRONEOUS SPECIFICATIONS FOR SEEDING

EXAMPLE U: "Hydroseeding" frequently is specified. Hydroseeding is an inappropriate technique for wetland replacement. Should water levels at the wetland replacement site rise above the seeded area prior to seed germination and seedling establishment, the mulch, binder, and seed/seedlings will float and wash away and deposit along the shoreline, with possible impacts.

EXAMPLE V: Seeding rates (i.e., pounds or liters per acre) specified are totally arbitrary and erroneous, since there is no information in the literature regarding the number of seeds per pound (or liter) for wetland plant species. Few nurseries list/carry wetland plant seeds, and fewer offer pure live seeds (pls) together with recent seed germination, seed purity results, and recommended seeding rates.

Other than for *Spartina alterniflora*, the only current sources of pure live seed in quantities sufficient to seed one acre or more are natural wetlands. Yet the quantities of seed readily available in natural wetlands for many of the major wetland plant species are limited because of:

- Poor seed production
- Seed damage from insects and fungi

- Inaccessibility

- Permission for collection not obtainable

If specifications require the collection of large quantities of seeds of native (local) species, the quantities of available seeds for major plant species will be severely limited.

A few nurseries and seed suppliers provide wetland seed mixes. However, these mixes often contain invasive species or species with limited habitat value and limited tolerance to wide hydrologic regimes. If such mixes are being considered for use, be certain to evaluate them for:

- Suitability of the species to the site conditions

- Capability of being successfully seeded, considering the site conditions

- Suitability of the species in achieving the stated goals and objectives of the wetland replacement

INVASIVE SPECIES

Beware! Commercial seed mixes often contain invasive species.

It is strongly recommended that seeding NOT be specified for any wetland plant species unless the following questions can be answered:

- What is the recommended seeding rate for the species (pls per sq ft, pls per acre, etc.) and what quantity (pounds, liters, etc.) of seed will be required?

- Will the required quantity of pure live seed be available

  - Commercially?

  - By nursery production under separate contract by the project sponsor?

  - By field collection under separate contract by the project sponsor?

  - By field collection under subcontract by the prime contractor?

- If field collection is necessary, where is the site located and is it large enough to provide the required quantity of seed?

- Can the species be seeded under the designed hydrologic conditions at the site (i.e., under water, if seeding is specified at elevations lower than the designed pool level, or at any tide condition, if site is tidal) with confidence that the seed will germinate and the seedlings will emerge? Or must the seeding be completed in the dry (water pumped out of site to several inches of water depth, if nontidal, or at low tide, if tidal)?

- If seeding must be accomplished in the dry, at what point after seeding may the designed hydrology be returned to the site with the assurance that seed germination and seedling development will occur satisfactorily?

- If seeding can succeed either in the dry or under water, what are the detailed specifications for each?

G.7.2 WETLAND PLANT SPECIES THAT CAN BE SUCCESSFULLY SEEDED

G.7.2.1 Herbaceous Species

Table G-14 contains information about the seed of herbaceous wetland plant species that can be successfully seeded under nursery and, for some, field conditions.

When nursery seeding, the seeds of species containing 500,000 seeds and more per pound are generally mixed (diluted) with sand so that unit volumes of the mixture will provide the desired seedling densities per unit areas (based on pure live seed). These sand/seed mixtures then are spread over the areas to be seeded, followed by pressing seed into contact with the substrate.

Whether seeding in the nursery or in the field, do not cover or bury plants by more than twice the thickness of the seed.

The seeds of species with less than 500,000 seeds per pound are similarly treated; but, after spreading the sand/seed mixture and pressing seed into contact with the substrate, additional sand or substrate is spread over the seeded area at a depth equal to or less than twice the thickness of the seed.

When field seeding, those species containing 500,000 seeds or more per pound should be surface sown and pressed into contact with the substrate and layered with a thin film of silt/mud. The seeds of those species that contain less than 500,000 seeds per pound should be subsurface sown to depths that do not exceed twice the thickness of the seed.

Of all the seeds listed in Table G-14, only *Scirpus pungens* is more dense than water when it shatters and falls from the plant. This seed will fall through the water column, settling on the underlying sediments. Water or wind generally will not carry it for colonization in other locations in the wetland.

The other seeds listed in Table G-14 initially will float after they fall from the plants. In time, these seeds will become waterlogged and sink, with the exception of *Peltandra virginica*. Because they initially float, many of the seeds of these species are blown on the water to one side or the other of the wetland and deposited along with other wrack on the shoreline. The smaller seeds (1,000,000 seeds or more per pound) in Table G-14 can become wind-borne as they shatter from the plants and be carried large distances from their point of origin. Probably none of the species in Table G-14 can be transported greater distances than *Peltandra virginica*. Seed of this species can float for 6 - 8 months after separating from its pod and, literally, end up in the ocean hundreds of miles from its origin up river.

AN EXAMPLE OF AN UNUSUAL SEED

EXAMPLE W: Of all of the seeds listed in Table G-14, *Peltandra virginica* is the most unusual. It is the largest seed listed and produces the smallest plant after one full growing season. Two years are required for the seedling to flower. The seed floats until the germination process begins. At this time, the seed coat ruptures and a large gelatinous mass envelopes the seed. The density of the seed with gelatinous mass (group) is greater than water and the group falls down through the water column and settles on the bottom.

The seedling will root only in soft muddy sediments. Its roots are so thick and non-fibrous that they push a buried seedling out into the air/water, unless the soils are soft enough for the thick roots to penetrate. The seeds must be sown deep (>1"), or they may float out of the soil prior to germination. Thus, successful field seeding may not always be possible (discussion follows).

Several species that have been successfully seeded at field-scale levels are discussed in detail below. Species in Table G-14 that have been successfully seeded in the nursery have potential for field-seeding; however, detailed specifications cannot be provided. If field-seeding is specified for any of them, it should be done so at modest experimental levels to avoid risking the overall success of the wetland replacement project. Always specify seeding "in the dry," unless seeding is known to work "in the wet."

Unless the water to be associated with the replacement wetland is known to have unusually high nutrient loads, primarily nitrogen, a one-time fertilization at the time of seeding for nontidal wetlands and following seeding for tidal wetlands should be specified. If fertilization is conducted as specified, the fertilizer used should not lead to the contamination of the waters interacting with the replacement wetland: the fertilizer will be surrounded by mineral soils, and any nutrients released will become adsorbed by the soils, rather than released into the water column.

The recommended seeding and fertilization technique for some species follows below. Table G-15 summarizes individual seeding rates for each of the species discussed. However, this rate is for seeding the species alone. If seeding more than one species, rates should be adjusted.

WETLAND SEEDING

- Most seeds float after falling from the plant and will be blown on the water and deposited on the wetland shores.

- If field-seeding species that have not been previously seeded successfully, do so only in small experimental plots to avoid risking the entire replacement project.

G.7.2.1.1 ***Agrostis alba*** **(Red Top):** Red top germinates fast for rapid soil stabilization, is not invasive, and is commercially available. It is only suitable for use on sites that are seasonally or irregularly flooded. Use the seeding and fertilizing technique recommended below. After seeding in the dry, the hydrology for the wetland replacement site can be established. If seeding alone, the recommended seeding rate is five pounds of pure live seed (pls) per acre.

This seeding rate provides about twenty pls per sq ft. If co-seeding with other species, the rate should be reduced to provide the desired relative representations of all of the species specified. If site conditions allow, more conventional seeding using a tractor and cultipactor is acceptable. However, the cultipactor should be set just to scarify the sediments to avoid placing the seeds deeper than 1/8 inch. Specify that the tractor or ATV traverse the site three times using different patterns to assure good seed/soil contact and avoid a "row" appearance of the plants.

G.7.2.1.2 *Bidens connata* (Beggar's Tick) and Other *Bidens* Species: Beggar's tick and other *Bidens* species are annual plants that readily reseed. On one wetland replacement site, *B. connata* has persisted for five years with no indication of disappearing. They provide brilliant fall color for people to enjoy; however, they have little wildlife value. The hydrologies associated with riparian and depressional wetlands often are suitable for its germination and development (i.e., flooding early in the growing season and occasionally thereafter). It may be co-seeded with red top and switchgrass, which adapt to the same wetland hydrology.

RECOMMENDED SEEDING AND FERTILIZATION TECHNIQUE

This technique is recommended when seeding Agrostis alba, Bidens spp., Leersia oryzoides, Panicum virgatum, and Typha spp. in the dry, in NONTIDAL areas. See text for other details on seeding each individual species.

Before seeding (i.e., can be three to six months earlier), the area to be seeded should be decompacted through discing, rototilling, or ripping of the sediments to a depth of no less than four inches.

The best time to seed is at the beginning of the growing season. Seeding in the fall, winter, or early spring risks the loss of seed (i.e., washing out) before germination and rooting in the sediments. Also, freezes may kill seedlings that germinate early. The seed should be thoroughly mixed with 3 times its volume of sand and the sand/seed mixture broadcast in an even coverage by hand or by use of a "cyclone seeder."

Following sand/seed broadcasting, eight- to nine-month release OSMOCOTE 18-6-12 fertilizer, or a comparable brand, should be broadcast at a rate of 300 lbs. per acre. The seed and fertilizer then must be pressed into good contact with the sediments and covered by a thin (less than 1/8 inch) film of silt/mud. Use of an ATV pulling a weighted flat-bottom drag (no bolts) is effective. For small areas, walking over the area using the back side of a garden rake to cover the seeds should be effective.

A seeding rate of one pound of pls per acre will provide three pls per sq ft. This is a suitable rate if co-seeded with other perennial species or if seeding alone followed by transplanting with perennial species. Beggar's tick should never be seeded alone if no other perennial herbaceous species will be planted because alone it would not provide the sediment stabilization and erosion control required. The Beggar's tick, together with any additional species, should be seeded in the dry using the seeding and fertilization technique recommended above. The wetland replacement site can receive the designed hydrology immediately after seeding. If site conditions allow, more conventional seeding using a tractor and cultipactor is acceptable; however, the cultipactor should be set just to scarify the sediments to avoid placing the seeds deeper than 1/8 inch. Specify that the tractor or ATV should traverse the site three times using different patterns to assure good seed/soil contact and avoid a "row" appearance of the plants.

PURE LIVE SEED

Specify pure live seed only. Do not use freshly harvested seed that has yet to break dormancy.

G.7.2.1.3 *Leersia oryzoides* (Rice Cutgrass): Rice cutgrass must be seeded in the dry (wet, but drained sediments with less that 10% standing water less than 0.5 inches deep), as the seeds float for long periods of time. Seed at the beginning of the growing season at a rate of 10 pls per sq ft. This rate requires 0.75 pounds of pls per acre. Specify that the supplier provide germination test results performed within the past three months and documentation of seed purity on or prior to delivery. In the Mid-Atlantic region, this seed requires up to six months of cold storage to break dormancy and to achieve a maximum germination percentage.

TABLE G-15

SUGGESTED SEEDING TABLES

Seeding rates are for seeding species alone. If seeding more than one species, rates should be adjusted. Refer to text for explanations for seeding rate given.

Species	Seeding Rate (pure live seed)	Density Provided
Agrostis alba	5 lbs. per acre	20 pls per sq ft
Bidens spp.	1 lb. per acre	3 pls per sq ft
Leersia oryzoides	0.75 lb. per acre	10 pls per sq ft
Panicum virgatum	10 lbs. per acre	70 pls per sq ft
Peltandra virginica	10 lbs. per acre	0.11 pls per sq ft
Spartina alterniflora	12.5 Liters per acre (seeds stored wet)	10 pls per sq ft
Typha spp.	0.10 lb per acre	100 pls per sq ft

Use the recommended seeding and fertilization technique. After seeding, maintain dry conditions (saturated soils with less than one inch of standing water) until seed germination is complete and seedlings are two to three inches tall. At that time, the designed hydrology may be returned to the site.

Rice cutgrass will tolerate six inches of water for extended periods of time, as well as periodic droughty conditions.

If seeding rice cutgrass in tidal freshwater conditions, the general specifications given apply. However, no alteration of the tidal hydrology, diversion of tidal water, or control of water depths should be specified. For tidal wetlands, the seeding should be specified during periods when the tide is drained from the site. Appropriate elevations to seed range from Mean High Water (MHW) to 10% of the intertidal range below MHW. Use biological benchmarks, if available, to confirm the appropriate elevation range to seed (Chapter 2). Fertilize as specified for cordgrass (*Spartina alterniflora*).

G.7.2.1.4 *Panicum virgatum* (Switchgrass): There are many varieties of switchgrass: the most suitable for wetland specifications is **BLACKWELL**. This variety and others are readily available commercially. Use the recommended seeding and fertilizing technique. The wetland replacement site can receive the designed hydrology immediately after seeding. If seeding alone, the recommended rate is 10 pounds of pls per acre. This rate provides about 70 pls per sq ft. This rate is 7 times higher than recommended for rice cutgrass and cordgrass because switchgrass is a bunch grass and has a slow rate of spread (Section G.6.2). If co-seeding with other species, the rate should be reduced to provide the desired relative representations of all of the species specified. Switchgrass requires 2 growing seasons to mature to a flowering plant.

G.7.2.1.5 *Peltandra virginica* (Arrow Arum): As discussed earlier, the seed of arrow arum is unique among herbaceous wetland plant species. Mechanical field scale seeding of it has not been successful for reasons stated earlier. Successful seeding of the species requires that soils at the wetland replacement site be deconsolidated (decompacted) to a depth of eight inches rather than four inches, as suggested in the recommended seeding technique.

Prior to seeding, the seed coats should be ruptured by rubbing the seed on a wire screen. This increases seed germination to near 100%. Rubber gloves should be worn by persons preparing the seed: it contains a chemical or chemicals that lead to severe skin rashes. The plant is known to contain caustic calcium oxalate, which is why the leaves and rootstock are not consumed by wildlife. Only wood ducks are known to eat the seed.

Seeding should be completed in the dry at the beginning of the growing season. One seed (with ruptured seed coat), together with one teaspoon of eight- to nine-month release OSMOCOTE® 18-6-12 fertilizer should be placed in planting holes two to three inches in depth and the holes then backfilled with soil. Seeds must be firmly packed in the planting holes or they will float out. Planting holes should be three feet on-center. This requires 10 pounds of pls and 54 pounds of fertilizer per acre of area seeded. After seeding, the site may be returned to the designed hydrology. For tidal sites, seed at times when the tide is drained from the site.

Arrow arum is a bulb and does not spread vegetatively. The seed it produces is not likely to reseed near the plant that produced it, since it probably will float away after separating from its pod. Consequently, the specifications given above will provide an arrow arum plant every three feet throughout the wetland replacement site. If a plant density higher than three feet on-center is desired, plant at that density. Wetland replacement sites planted with arrow arum still show the original planting grid after seven years, with only annual plant species filling in between the original plant sites.

It will take two years for arrow arum seedlings to mature to flowering plants. The first year the seedlings will appear minuscule; however, during the second and following years, aerial coverage of the site by the plants will appear uniform or nearly so and other annual and perennial plant species will probably volunteer the space between the arrow arum plants. Because of their slow rate of growth, arrow arum is vulnerable to wave energies, sediment deposits on its leaves, and trampling.

G.7.2.1.6 *Spartina alterniflora* (Cordgrass): Hundreds of acres of saltmarsh have been successfully created by seeding cordgrass. Successful seeding results in substantially higher density first-year coverage than can be achieved by transplanting. High ground coverage is important if Canada geese are in the area seasonally or year-round, since they normally feed on the wetland edge when the interior plant density is high.

The recommended seeding rate is 10 pls per sq ft: mix the seed (drained of its storage water) with one fourth its volume of regular cat litter. This dries and dilutes the seed to facilitate even distribution. The seed should be distributed by hand, as mechanical distribution methods either damage the seed or clog the mechanical device with chaff. When seeding in the dry with the tide drained from the site, seed must be subsurface sown to depths of no greater than one-half inch. All Terrain Vehicles (ATVs) equipped with weighted drags that contain rows of bolts set at the correct depths have been found to be useful in seeding.

SEEDING CORDGRASS

Cordgrass cannot be seeded successfully in areas where there is ponded water at low tide or where sediments are soft and poorly drained (Appendix J.3.14).

Cordgrass can be seeded successfully in the wet using an airboat equipped with a drag of chains across the stern. This method is particularly useful, particularly if the substrate will not support an ATV. The seed can be distributed with either the tide covering the site (from the airboat) or drained from the site. Either way, the seed ends up on the substrate surface, as it has a higher density than saltwater (the seed normally is stored refrigerated in 40 ppt saltwater). After seed has been broadcast and tidal water covers the site, the airboat with chain drag circles about, stirring up the bottom sediments which slowly re-settle, covering the seed.

Seeding is limited to the upper 30% to 40% of the intertidal range. Even though cordgrass will grow to lower elevations, the initially slow-growing seedlings often will become covered by silt and/or diatoms at these elevations, due to the longer hydroperiods, and they will not survive.

Seeding should be completed in May in the northeast if the seedlings are to flower the first year and to assure that the seedlings will be mature enough to overwinter. In areas where the nutrient levels in the water are high (e.g., when native cordgrass is taller than five feet), fertilization following seeding is not recommended. In other areas where nutrient levels are normal (cordgrass three-to-five feet tall), fertilization is recommended at two and four months after seeding. For each fertilization, a 10-10-10 fast-release fertilizer is recommended to be broadcast at a rate of 300 pounds per acre at ebb tide as water recedes from the site.

USE OF CATTAILS

Many consider cattails to be invasive. They are also known to be allopathic. Specify their use with caution.

G.7.2.1.7 ***Typha* spp. (Cattail):** For best results, cattail species should be seeded and fertilized in the dry at the beginning of the growing season, as described in the recommended seeding and fertilization technique. The recommended seeding rate of 0.10 pound of pls per acre will provide about 100 pls per sq ft. This rate is recommended because cattail seedlings are so delicate and vulnerable immediately after germination that most will not survive. The site may be returned to the designed hydrology following seeding; however, if the flooding water has a high turbidity, it is best to maintain water depths under six inches at nontidal sites until the plants are about one foot tall. At tidal sites, there should be no manipulation of hydrology.

G.7.2.2 Woody Species

There is a shortage of information about direct seeding of trees and shrubs. The only species that can be reliably direct-seeded are oaks. Seeding acorns manually or mechanically two to three inches deep during the dormant season often is successful, although squirrels and chipmunks may exhume them. Direct seeding of other species has resulted in patchy or low diversity stands at best and should not be specified until techniques and procedures with more reliable results have been developed and reported. Specify planting instead, but not of bare-root plants.

COVER & UNDERSTORY SEEDING

- For cover crops, look into native bunch grasses with wildlife value as food and cover and tolerance to flooding. The local SCS and Extension Service may be of help.
- It is difficult enough to achieve successful plant establishment without competition from understory plants. Do not seed over planted trees and shrubs!

G.7.3 SEEDING UNDERSTORY OR COVER CROPS IN FORESTED AND SCRUB-SHRUB WETLAND REPLACEMENTS

For purposes of sediment stabilization and erosion control, food and cover for wildlife, and nutrient recycling, the seeding of cover crops always should be specified, particularly for seasonally or irregularly flooded wooded wetlands. In more permanently flooded wetland types, cover crops might be group-planted or planted at a low density. Species suitable for cover crop seeding are nonaggressive species, often bunch grasses. *Panicum virgatum; Agrostis alba,* and *Bidens* spp. are suitable. Often certain upland species also would be suitable for use on seasonally or temporarily flooded sites. The regional Soil Conservation Service or Extension Service are good local sources for information about appropriate species. Under no circumstances should rhizome-propagating, turf-forming grass seed be specified.

When specifying the seeding of cover crops in wooded wetlands, tree and/or shrub planting should be completed first, then the site should be seeded. Seed should not be broadcast, as seed would likely be placed over the tree and/or shrub planting sites. It should be specified that seed be dropped between the plants from a "bin" seeder pushed/pulled by hand or by a tractor or ATV, and that great care be taken to ensure that no seeds are distributed over the plants.

G.8 REFERENCES CITED AND BIBLIOGRAPHY

Many of the following references were consulted in preparing Tables G-1 through G-9 and G-14; however, they are not explicitly referenced in these tables or in the text.

Aberle, B. 1990. The Biology, Control, and Eradication of Introduced *Spartina* (cordgrass) Worldwide and Recommendations for Its Control in Washington (Draft). Washington Department of Natural Resources, Olympia, Washington. 88 pp.

Abrams, L. 1923. Illustrated Flora of the Pacific States: Washington, Oregon, and California. Volume I: *Ophioglossaceae* to *Aristolochiaceae*. Stanford University Press, Standford, California. 557 pp.

___. 1944. Illustrated Flora of the Pacific States: Washington, Oregon, and California: Volume II: *Polygonaceae* to *Krameriaceae*. Stanford University Press, Stanford, California. 635 pp.

___. 1951. Illustrated Flora of the Pacific States: Washington, Oregon, and California. Volume III: *Geraniaceae* to *Scrophulariaceae*. Stanford University Press, Stanford, California. 866 pp.

___. 1960. Illustrated Flora of the Pacific States: Washington, Oregon, and California. Volume IV: *Bignoniceae* to *Compositae*, Stanford University Press, Stanford, California. 732 pp.

Allen, H.H. and C.V. Klimas. 1986. Reservoir Shoreline Revegetation Guidelines. Technical Report E-86-13. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Allen, L.S. and J.P. Rieger. 1980. Biological Impact Study of 8/15 Interchange (River Area). SD-15 R6.0/R7.0 SD-08 5.1/6.3. California Department of Transportation, Environmental Analysis Branch, San Diego County, California.

American Association of Nurserymen, Inc. 1980. American Standard for Nursery Stock. Washington, DC. 30 pp.

Anderson, B.W. and R.D. Ohmart. 1985. Riparian revegetation as a mitigating process in stream and river restoration, pp. 41-49. In J.A. Gore (Ed.), The Restoration of Rivers and Streams: Theories and Experience. Butterworth Publishers, Boston, Massachusetts.

Barnhart, R.K. 1986. The American Heritage Dictionary of Science. Houghton Mifflin Co., Boston, Massachusetts. 740 pp.

Bartoldus, C.C. and F.D. Heliotis. 1989. Factors Affecting the Survival of Planted Material in the Marley Creek Constructed Freshwater Tidal Marsh, Maryland. Transportation Research Board 68th Annual Meeting. Washington, DC.

Baskett, T.S., D.A. Darrow, D.L. Hallett, M.J. Armbruster, J.A. Ellis, B.F. Sparrowe, and P.A. Korte. 1980. A Handbook for Terrestrial Habitat Evaluation in Central Missouri. Resource Publication 133. U.S. Fish and Wildlife Service, Washington, D.C.

Beal, E.O. 1977. A Manual of Marsh and Aquatic Vascular Plants of North Carolina with Habitat Data. The North Carolina Agricultural Research Service, Raleigh, North Carolina.

Berge, D.A. 1987. Native plants, fish introduced in lake restoration effort (Wisconsin). Restoration & Management Notes 5(1):35.

Best, R.G. and K.L. Erwin. 1984. Effects of hydroperiod on survival and growth of tree seedlings in a phosphate surface-mined reclaimed wetland, pp. 221-225. In D. Graves (Ed.), Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. University of Kentucky, Lexington, Kentucky.

Broadfoot, W.M. and H.L. Williston. 1973. Flooding effects on southern forests. Journal of Forestry 71:584-587.

Broome, S.W. 1989. Creation and restoration of tidal wetlands of the United States, pp. 37-72. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science Vol. I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Broome, S.W., E.D. Seneca, and W.W. Woodhouse, Jr. 1982. Establishing brackish marshes on graded upland sites in North Carolina. Wetlands 2:152-178.

___. 1983. Creation of brackish-water marsh habitat pp. 319-338. Publication No. 03-036-010. In Reclamation and the Phosphate Industry, Proceedings of the Symposium. Florida Institute of Phosphate Research, Clearwater Beach, Florida.

___. 1988. Tidal salt marsh restoration. Aquatic Botany 32:1-22.

Brown, R.G. and M.L. Brown. 1972. Woody Plants of Maryland. Port City Press, Baltimore, Maryland. 347 pp.

___. 1984. Herbaceous Plants of Maryland. Port City Press, Baltimore, Maryland. 1127 pp.

Carlton, J.M. 1975. A Guide to Common Florida Salt Marsh and Mangrove Vegetation. Florida Marine Research Publication No. 6. Florida Department of Natural Resources, St. Petersburg, Florida.

Cathey, H.M. 1990. U.S. Department of Agriculture Plant Hardiness Zone Map. U.S. Department of Agriculture, Washington D.C.

Chabreck, R.H. 1989. Creation, restoration, and enhancement of marshes of the Northcentral Gulf Coast, pp. 127-144. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science Vol. I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Chabreck, R.H., B.K. Pilcher, and A.B. Ensiminger. 1983. Growth, production, and wildlife use of Delta Duckpotatoes in Louisiana, pp. 56-66. In J.M. Sweeney and J.R. Sweeney, K.C. Sweeney, P. Doerr, and L. Wilson (Eds.), Proceedings of the Thirty-Seventh Annual Conference of the Southeastern Association of Fish and Wildlife Agencies. Asheville, North Carolina.

Clark, J.R. and J. Benforado. 1981. Wetlands of Bottomland Hardwood Forests: Proceedings of a Workshop on Bottomland Hardwood Forest Wetlands of the Southeastern United States. Elsevier Scientific Publishing Company, Amsterdam, The Netherlands.

Clewell, A.F. 1981. Vegetational restoration techniques on reclaimed phosphate strip mines in Florida. Wetlands 1:158-170.

____. 1989. Creation and restoration of forested wetland vegetation in the southeastern United States, pp. 199-238. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science Vol. I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Clewell, A.F., J.A. Goolsby, and A.G. Shuey. 1982. Riverine forests of the South Prong Alafia River System, Florida. Wetlands 2:21-72.

Day, E.A. 1986. Mitigation for the South Madison Beltline: Dane County, WI. Wisconsin Department of Transportation.

Degraaf, R.M. and G.M. Witman. 1979. Trees, Shrubs, and Vines for Attracting Birds: A Manual for the Northeast. University of Massachusetts Press, Amherst, Massachusetts.

Detweiler, T., F.M. Dunstan, R.R. Lewis III, and W.K. Fehring. 1975. Patterns of secondary succession in a mangrove community, Tampa Bay, Florida, pp. 52-80. In R.R. Lewis III (Ed.), Proceedings for the Second Annual Conference on the Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Dickerson, J. 1991. The 'native plant' issue. The Newsletter for The U.S. Department of Agriculture Soil Conservation Service Plant Materials Program in New York, Vermont, New Hampshire and Maine 3(4).

Dodd, J.D. and J.W. Webb. 1975. Establishment of vegetation for shoreline stabilization in Galveston Bay. Misc. Paper No.6-75. U.S. Army Corps of Engineers, Fort Belvoir, Virginia.

Dubinski, B.J., C.S. Nordby, S.D. Perry, J.D. Covin, and J.B. Zedler. 1987. Artificial wetlands to enhance estuarine ecosystems in southern California, pp. 170-171. In K.M. Mutz and L.C. Lee (Technical Coordinators), Wetland and Riparian Ecosystems of the American West: Eighth Annual Meeting of the Society of Wetland Scientists. Society of Wetland Scientists, Seattle, Washington.

Duncan, W.H. and M.B. Duncan. 1988. Trees of the Southeastern United States. The University of Georgia Press, Athens, Georgia.

Eleuterius, L.N. 1974. A Study of Plant Establishment on Spoil Areas in Mississippi Sound and Adjacent Waters. U.S. Army Corps of Engineers, Mobile, Alabama.

Elias, T.S. 1987. The Complete Trees of North America: A Field Guide and Natural History. Gramercy Publishing Company, New York, New York. 948 pp.

Environmental Concern, Inc. 1984. Shrubs and Trees for Wildlife Habitat Development. St. Michaels, Maryland. 7 pp.

___. 1984. Plants for Landscaping Shores, Ponds and Other Wet Areas. St. Michaels, Maryland. 5 pp.

Environmental Laboratory. 1978. Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation. Technical Report DS-78-16. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

___. 1987. Corps of Engineers Wetlands Delineation Manual. Technical Report Y-87-1. U.S. Army Waterways Experiment Station, Vicksburg, Mississippi.

Erickson, N.E. and D.M. Leslie, Jr. 1987. Soil-Vegetation Correlations in the Sandhills and Rainwater Basin Wetlands of Nebraska. Biological Report 87(11). U.S. Fish and Wildlife Service, Washington, DC.

Erwin, K.L., R.G. Best, W.J. Dunn, and P.M. Wallace. 1985. Marsh and forested wetland reclamation of a central Florida phosphate mine. Wetlands 4:87-104.

Erwin, K.L. 1989. Freshwater marsh creation and restoration in the southeast, pp. 239-271. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science Vol. I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Faber, P.M., E. Keller, A. Sands, and B.M. Massey. 1989. The Ecology of Riparian Habitats of the Southern California Coastal Region: A Community Profile. Biological Report 85(7.27). U.S. Fish and Wildlife Service, Washington, DC. 152 pp.

Fernald, M.L. 1987. Gray's Manual of Botany; Eighth Edition. Dioscorides Press, Portland, Oregon. 1632 pp.

Fonseca, M.S. 1992. Restoring Seagrass Systems in the United States. In G.W. Thayer (Ed.), Restoring the Nation's Marine Environment. Maryland Sea Grant College, University of Maryland. College Park, MD.

Fonseca, M.S., W.J. Kenworthy, and G.W. Thayer. 1992. Seagrass meadows: nursery for coastal species pp. 141-147. In R.H. Stroud (Ed.), Stemming the Tide of Coastal Fish Habitat Loss: A Symposium On Coastal Fish Habitat Conservation. National Coalition for Marine Conservation. Savannah, Georgia.

Fonseca, M.S., and W.J. Kenworthy. 1979. Transplanting of eelgrass and shoalgrass as a potential means of economically mitigating a recent loss of habitat pp. 279-326. In D.P.Cole (Ed.), Proceedings of the Sixth Annual Conference on Wetlands Restoration and Creation. Hillsborough Community College, Tampa, Florida.

Fonseca, M.S., W.J. Kenworthy, K. Rittmaster, and G.W. Thayer. 1987. The Use of Fertilizer to Enhance Transplants of the Seagrasses *Zostera marina* and *Halodule wrightii*. Technical Report EL-87-12. U.S. Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

Garbisch, E.W., Jr. 1986. Highways & Wetlands: Compensating Wetland Losses. Contract Report DOT-FH-11-9442. Federal Highway Administration, Office of Implementation, McLean, Virginia.

___. 1989. Wetland enhancement, restoration, and construction, pp. 261-275. In S.K. Majumdar, R.P. Brooks, F.J. Brenner, and R.W. Tiner, Jr. (Eds.), Wetlands Ecology and Conservation: Emphasis in Pennsylvania. The Pennsylvania Academy of Science, Phillipsburg, New Jersey.

Garbisch, E.W., Jr. and L.B. Coleman. 1978. Tidal freshwater marsh establishment in upper Chesapeake Bay; *Pontederia cordata* and *Peltandra virginica*, pp. 285-298. In R.E. Good, D.F. Whigham, and R.L. Simpson (Eds.), Freshwater Wetlands: Ecological Processes & Management Potential. Academic Press, New York.

Gleason, H.A. 1952. The New Britton and Brown Illustrated Flora of the Northeastern United States and Adjacent Canada. Hafner Press for the New York Botanical Garden, New York, New York.

Godfrey, R.K. and J.W. Wooten. 1979. Aquatic and Wetland Plants of Southeastern United States: Monocotyledons. The University of Georgia Press, Athens, Georgia. 712 pp.

___. 1981. Aquatic and Wetland Plants of Southeastern United States: Dicotyledons. The University of Georgia Press, Athens, Georgia. 933 pp.

Goforth, H.W., Jr. and J.R. Thomas. 1979. Plantings of red mangroves (*Rhizophora mangle* L.) for stabilization of marl shorelines in the Florida Keys, pp. 207-230. In D.P. Cole (Ed.), Proceedings of the Sixth Annual Conference On the Restoration & Creation of Wetlands. Hillsborough Community College, Tampa, Florida.

Goforth, H.W., Jr. and M. Williams. 1983. Survival and growth of red mangroves (*Rhizophora mangle* L.) planted upon marl shorelines in the Florida Keys (a five year study), pp. 130-148. In F.J. Webb, Jr. (Ed.), Proceedings of the Tenth Annual Conference on Wetland Restoration and Creation. Hillsborough Community College, Tampa, Florida.

Gosselink, J.G. 1984. The Ecology of Delta Marshes of Coastal Louisiana: A Community Profile. FWS/OBS-84/09. U.S. Fish and Wildlife Service, Washington, DC.

Gouin, F.R. Desirable Soil pH and Salt Tolerance of Ornamental Plants. Cooperative Extension Service: Horticulture Production. University of Maryland, College Park, Maryland.

Gunderson, L.H., J.R. Stenberg, and A.K. Herndon. 1988. Tolerance of five hardwood species to flooding regimes, pp. 119-132. In D.A. Wilcox (Ed.), Interdisciplinary Approaches to Freshwater Wetlands Research. Michigan State University Press, East Lansing, Michigan.

Guntenspergen, G.R., F. Stearns, and J.A. Kadlec. 1989. Wetland vegetation, pp. 73-88. In D.A. Hammer (Ed.), Constructed Wetlands for Wastewater Treatment. Lewis Publishers, Chelsea, Michigan.

Gutshall, M.A. 1987. More diverse shrubs for created freshwater wetlands, pp. 176-179. In K.M. Mutz and L.C. Lee (Eds.), Wetland and Riparian Ecosystems of the American West. Eighth Annual Meeting of the Society of Wetland Scientists. Society of Wetland Scientists, Seattle, Washington.

Hall, W.C. and S.M. Naik. 1989. Determination of Effectiveness of Required Environmental Mitigation Activities Related to the Construction of Highways in Florida. FL Department of Transportation, Bureau of Environment, Tallahassee, Florida. 131 pp.

Harvey & Stanley Assoc. 1983. Revegetation Manual for the Alameda County Flood Control and Water Conservation District Revegetation Program. County of Alameda Public Works Agency, Hayward, California.

Harvey, H.T., P. Williams, and J. Haltiner. 1982. Guidelines for Enhancement and Restoration of Diked Historic Baylands. San Francisco Bay Conservation and Development Commission, San Francisco, California. 38 pp.

Haynes, R.J., J.A. Allen, and E.C. Pendleton. 1988. Reestablishment of Bottomland Hardwood Forests on Disturbed Sites: An Annotated Bibliography. Biological Report 88(42). U.S. Fish and Wildlife Service, Washington, DC.

Herbold, B. and P.B. Moyle. 1989. The Ecology of the Sacramento-San Joaquin Delta: A Community Profile. Biological Report 85(7.22). U.S. Fish and Wildlife Service, Washington, DC.

Hightshoe, G.L. 1988. Native Trees, Shrubs, and Vines for Urban and Rural America: A Planting Design Manual for Environmental Designers. Van Nostrand Reinhold, New York. 819 pp.

Hollands, G.G. 1989. Regional analysis of the creation and restoration of kettle and pothole wetlands, pp. 287-304. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science Vol. I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Hotchkiss, N. 1972. Common Marsh, Underwater & Floating-leaved Plants of the United States and Canada. Dover Publications, New York. Two parts: 99 pp. and 124 pp.

Hurley, L.M. 1990. Field Guide to the Submerged Aquatic Vegetation of Chesapeake Bay. U.S. Fish and Wildlife Service, Annapolis, Maryland.

Illinois Department of Conservation. 1981. Illinois Plants for Habitat Restoration; Commercial Availability, Characteristics and Fish & Wildlife Utilization. Illinois Department of Conservation Mining Program, Springfield, Illinois. 61 pp.

Jackson, J.O. 1989. Preliminary Report on Wetland Planting and Seeding Evaluation for the Madison South Beltline Mitigation Project in 1988. Wisconsin Department of Transportation, Office of Environmental Analysis.

Josselyn, M.N. and J.W. Buchholz. 1984. Marsh Restoration in San Francisco Bay: A Guide to Design & Planning. Technical Report #3. Tiburon Center for Environmental Studies. San Francisco State University. 104 pp.

Kadlec, J.A. and W.A. Wentz. 1974. State-of-the-Art Survey and Evaluation of Marsh Plant Establishment Techniques: Induced and Natural. Volume I: Report of Research. Contract Report D-74-9. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Kantrud, H.A., G.L. Krapu, and G.A. Swanson. 1989. Prairie Basin Wetlands of the Dakotas: A Community Profile. Biological Report 85(7.28). U.S. Fish and Wildlife Service, Washington, DC. 116 pp.

Kartesz, J.T. and R. Kartesz. 1980. A Synonymized Checklist of the Vascular Flora of the United States, Canada, and Greenland. The University of North Carolina Press, Chapel Hill, North Carolina. 498 pp.

Kaufman, N. 1984. Sweetwater River Bridge Mitigation Report. 11-SD-94 PM T15.0/T15.5. California Department of Transportation, San Diego County, California.

Keeley, J.E. 1979. Population differentiation along a flood frequency gradient: physiological adaptations to flooding in *Nyssa sylvatica*. Ecological Monographs 49:89-108.

Kerans, K. 1990. The restoration business: Country Wetlands Nursery Ltd. Restoration & Management Notes 8(1):29-31.

Knutson, P.L. and W.W. Woodhouse, Jr. 1982. Pacific coastal marshes, pp. 111-130. In R.R. Lewis III (Ed.), Creation and Restoration of Coastal Plant Communities. CRC Press, Boca Raton, Florida.

Korschgen, C.E. and W.L. Green. 1988. American Wild Celery (*Vallisneria americana*): Ecological Considerations for Restoration. U.S. Fish and Wildlife Service, Washington, DC.

Kruczynski, W.L. 1982. Salt marshes of the Northeastern Gulf of Mexico, pp. 71-87. In R.R. Lewis III (Ed.), Creation and Restoration of Coastal Plant Communities. CRC Press, Boca Raton, Florida.

Laderman, A.D. 1989. The Ecology of Atlantic White Cedar Wetlands: A Community Profile. Biological Report 85(7.21). U.S. Fish and Wildlife Service, Washington, DC.

Landers, L., S. Johnson, P.H. Morgan, and W.P. Baldwin. 1976. Duck foods in managed tidal impoundments in South Carolina. Journal of Wildlife Management 40(4):721-728.

Landin, M.C., J.W. Webb, and P.L. Knutson. 1989. Long-Term Monitoring of Eleven Corps of Engineers Habitat Development Field Sites Built of Dredged Material, 1974-1987. Technical Report D-89-1. Department of the Army Waterways Experiment Station, Vicksburg, Mississippi.

Lawton, B.P. 1990. Plant Health: A Vital Link. American Nurseryman August 15.

Lemberger, J. 1981. Wildlife Nurseries Plant Catalog (What Brings Them In). Wildlife Nurseries, Oshkosh, Wisconsin.

Levine, D.A. and D.E. Willard. 1989. Regional analysis of fringe wetlands in the midwest: creation and restoration, pp. 305-332. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science Vol. I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Lewis, R.R., III. 1982. Mangrove forests, pp. 153-171. In R.R. Lewis (Eds.), Creation and Restoration of Coastal Plant Communities. CRC Press, Boca Raton, Florida.

___. 1989. Creation and restoration of coastal plain wetlands in Florida, pp. 73-101. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science Vol. I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Lewis, R.R., III and E.D. Estevez. 1988. The Ecology of Tampa Bay, Florida: An Estuarine Profile. Biological Report 85(7.18). U.S. Fish and Wildlife Service, Washington, DC.

Lindeman, W. and J.R. Wilt, Jr. 1988. Effectiveness of Mitigation Techniques at the Alafia River Crossing. Florida Department of Transportation, Environmental Research. 21 pp.

Marquis, D.A. 1981. Effect of Deer Browsing on Timber Production in Allegheny Hardwood Forests of Northwestern Pennsylvania. U.S. Department of Agriculture Forest Service. Research Paper NE-475. 10 pp.

Marquis, D.A. and R. Brenneman. 1981. The Impact of Deer on Forest Vegetation in Pennsylvania. General Technical Report NE-65. U.S. Department of Agriculture Forest Service. 7 pp.

Martin, A.C., H.S. Zim, and A.L. Nelson. 1951. American Wildlife & Plants, A Guide To Wildlife Food Habits. Dover Publications, New York. 500 pp.

McKnight, S.J., D. Hook, G.O. Langdon, and R.L. Johnson. 1981. Flood tolerance and related characteristics of trees of the bottomland forests of the southern United States, pp. 29-69. In J.R. Clark and J. Benforado (Eds.), Wetlands of Bottomland Hardwood Forests: Proceedings of a Workshop on Bottomland Hardwood Forest Wetlands of the Southeastern United States. Elsevier Scientific Publishing Company, Amsterdam, The Netherlands.

McLaughlin, P.A. and A. Thorhaug. 1978. Restoration of *Thalassia testudinum*: animal community in a maturing four-year-old site - preliminary results, pp. 148-161. In D.P. Cole (Ed.), Proceedings of the Fifth Annual Conference On the Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

Meehan-Martin, P.J. and D. Swanson. 1988a. Wetland Monitoring Report: Pacific Avenue Interchange SR 5. Washington State Department of Transportation, Environmental Unit.

___. 1988b. Wetland Monitoring Report: 128th Street Interchange. SR 5. Washington State Department of Transportation, Environmental Unit.

___. 1988c. Wetland Monitoring Report: North Creek Bridge 527/108 Replacement. SR527. Washington State Department of Transportation, Environmental Unit.

___. 1988d. Wetland Monitoring Report: Columbia Avenue/Marysville to SR 9/SR 528. Washington State Department of Transportation, Environmental Unit.

___. 1989. Wetland Monitoring Report: West Hoquiam Connection, Willapa Bay. SR 109. Washington State Department of Transportation, Environmental Unit.

Miller, H. and S. Lamb. 1985. Oaks of North America. Naturegraph Publishers, Happy Camp, California.

Mitsch, W.J and J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold Company, New York. 539 pp.

Moore, M.M. 1987. Environmental Study: Elk River Mitigation Project - 01-HUM-101-74.4, Annual Supplement. California Department of Transportation, Environmental Planning Branch. Eureka, California.

Newling, C.J. 1990. Restoration of bottomland hardwood forests in the Lower Mississippi Valley. Restoration & Management Notes 8(1):23-28.

Odum, W.E. and J.K. Hoover. 1988. A comparison of vascular plant communities in tidal freshwater and saltwater marshes, pp. 526-534. In D.D. Hook, W.H. McKee, Jr., H.K. Smith, J. Gregory, V.G. Burrell, Jr., M.R. DeVoe, R.E. Sojka, S. Gilbert, R. Banks, L.H. Stolzy, C. Brooks, T.D. Matthews, and T.H. Shear (Eds.), The Ecology and Management of Wetlands. Volume 1: Ecology of Wetlands. Timber Press, Portland, Oregon.

Odum, W.E., T.J. Smith, J.K. Hoover, and C.C. McIvor. 1984. The Ecology of Tidal Freshwater Marshes of the United States East Coast: A Community Profile. FWS/OBS-83/17. U.S. Fish and Wildlife Service, Washington, DC.

Owen, C.R., Q.J. Carpenter, and C.B. DeWitt. 1989. Evaluation of Three Wetland Restorations Associated with Highway Projects. Transportation Policy Studies Institute, WI Department of Transportation. Madison, Wisconsin. 89 pp.

Peterson, L.N. 1987. Wild celery transplanted (Wisconsin). Restoration & Management Notes 5(1):35-36.

Phillips, R.C. 1982. Seagrass meadows, pp. 173-210. In R.R. Lewis, III (Ed.), Creation and Restoration of Coastal Plant Communities. CRC Press, Boca Raton, Florida.

___. 1984. The Ecology of Eelgrass Meadows in the Pacific Northwest: A Community Profile. FWS/OBS-84/24. U.S. Fish and Wildlife Service, Washington, DC.

Pierce, G.J. 1990. Freshwater Emergent Marsh Restoration. Wetlands Development and Restoration. Corps of Engineers Training Management Division, Huntsville, Alabama.

Pierce, M.C. 1984. Diversity of Vegetation in Constructed and Natural Freshwater Emergent Marshes in Western New York. Masters Dissertation. Niagara University.

Platts, W.S., C. Armour, G.D. Booth, M. Bryant, J.L. Bufford, P. Cuplin, S. Jensen, G.W. Lienkaemper, G.W. Minshall, S.B. Monsen, R.L. Nelson, J.R. Sedell, and J.S. Tuhy. 1987. Methods for Evaluating Riparian Habitats With Applications to Management. General Technical Report INT-221. U.S. Department of Agriculture Forest Service, Ogden, Utah.

Plewa, F.R. 1987. A Guide to Wetland Plantings in Pennsylvania and Recommended Approaches to Establishing Vegetative Cover. Special Project Report No. 87-1. U.S. Fish & Wildlife Service, State College, Pennsylvania.

Pomeroy, W.M., D.K. Gordon, and C.D. Levings. 1981. Experimental Transplants of Brackish and Salt Marsh Species on the Fraser River Estuary. Department of Fisheries and Oceans Resources and Services, West Vancouver, British Columbia.

Priest, W.I. 1989. Wetlands Mitigation Evaluation: Vegetation Studies; Final Report to the City of Norfolk. The Virginia Institute of Marine Science, Gloucester Point, Virginia.

Reed, P.B. 1988. National List of Plant Species That Occur in Wetlands: 1988 National Summary. Biological Report 88(24). U.S. Fish and Wildlife Service, Washington, DC.

Ross, W.M. and R.H. Chabreck. 1972. Factors affecting the growth and survival of natural and planted stands of *Scirpus olneyi*, pp. 178-188. In A.L. Mitchell (Ed.), Proceedings of the Twenty-sixth Annual Conference. Southeastern Association of Game and Fish Commissioners, Knoxville, Tennessee.

Rydberg, P.A. 1969. Flora of the Rocky Mountains and Adjacent Plains. Hafner Publishing Company, New York. 1110 pp.

Schopmeyer, C.S. 1974. Seeds of Woody Plants in the United States. Agriculture Handbook No. 450. Forest Service, U.S. Department of Agriculture, Washington, DC. 883 pp.

Seliskar, D.M. and J.L. Gallagher. 1983. The Ecology of Tidal Marshes of the Pacific Northwest Coast: A Community Profile. FWS/OBS-82/32. U.S. Fish and Wildlife Service, Washington, D.C.

Seneca, E.D., S.W. Broome, W.W. Woodhouse, L.M. Cammen, and J.T. Lyon. 1976. Establishing *Spartina alterniflora* marsh in North Carolina. Environmental Conservation 3(3):185-188.

Shisler, J.K. 1989. Creation and restoration of coastal wetlands of the northeastern United States, pp. 145-174. In J.A. Kusler and M.E. Kentula (Eds.), Wetland Creation and Restoration: The Status of the Science Vol. I. U.S. Environmental Protection Agency, Corvallis, Oregon.

Smith, S.L. 1991. The hunt for sources. American Nurseryman Feb. 15:118-119.

Soil Conservation Service. 1992. Directory of Wetland Plant Vendors. Prepared for U.S. Army Corps of Engineers, Waterways Experiment Station, Wetlands Research Program Technical Report WRP-SM-1. Available from NTIS. ADA 259 566.

Southern Tier Consulting and Ecology & Environment. 1987. Wetland Demonstration Project. Allegheny River Floodplain. New York Department of Transportation.

Steenis, J.H. 1950. Waterfowl habitat improvement on Reelfoot Lake. Journal of the Tennessee Academy of Science 25:56-75.

Stephen, M.F. 1983. Mangrove restoration in Naples, Florida, pp. 201-216. In F.J. Webb, Jr. (Ed.), Proceedings of the Tenth Annual Conference on Wetland Restoration and Creation. Hillsborough Community College, Tampa, Florida.

Stephenson, M., G. Turner, P. Pope, J. Colt, A. Knight, and G. Tchobanoglous. 1980. The Use and Potential of Aquatic Species for Wastewater Treatment, Publication No. 63 - Appendix J: The Environmental Requirements of Aquatic Plants. California State Water Resources Control Board. Sacramento, California. 655 pp.

Stewart, R.E. and H.A. Kantrud. 1971. Classification of Natural Ponds and Lakes in the Glaciated Prairie Region. Resource Publication 92. Bureau of Sport Fisheries and Wildlife, Washington, DC. 57 pp.

Stout, J.P. 1984. The Ecology of Irregularly Flooded Salt Marshes of the Northeastern Gulf of Mexico: A Community Profile. Biological Report 85(7.1). U.S. Fish and Wildlife Service, Washington, DC.

Strausbaugh, P.D., and E.L. Core. Flora of West Virginia, Second Edition. Seneca Books, Grantsville, West Virginia. 1079 pp.

Streng, D.R., J.S. Glitzenstein, and P.A. Harcombe. 1989. Woody seedling dynamics in an east Texas floodplain forest. Ecological Monographs 59(2):177-204.

Sully, J.M. 1989. Conceptual Wetland Mitigation Plan for Moorpark Wetland Mitigation Site. 07-VEN 23/118 PM10.9/20.507203-050290. California Department of Transportation, Environmental Planning Branch, Ventura County, California.

Swenson, E.A. and C.L. Mullins. 1985. Revegetating riparian trees in southwestern floodplains, pp. 135-138. In R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Follist, R.H. Hamre (Technical Coordinators), Riparian Ecosystems and Their Management: Reconciling Conflicting Uses. 1st North American Riparian Conference. U.S. Department of Agriculture Forest Service. Tucson, Arizona.

Teal, J.M. 1986. The Ecology of Regularly Flooded Salt Marshes of New England: A Community Profile. Biological Report 85(7.4). U.S. Fish and Wildlife Service, Washington, DC.

Teas, H.J. 1977. Ecology and restoration of mangrove shorelines in Florida. Environmental Conservation 4(1):51-58.

Thorhaug, A. 1990. Restoration of mangroves and sea grasses - economic benefits for fisheries and mariculture, pp. 265-281. In J.J. Berger (Eds.), Environmental Restoration: Science and Strategies for Restoring the Earth. Island Press, Washington, D.C.

Tilghman, N.G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. Journal of Wildlife Management 53(3):524-532.

Tiner, R.W., Jr. 1987. A Field Guide to Coastal Wetland Plants of the Northeastern United States. The University of Massachusetts Press, Amherst, Massachusetts. 285 pp.

____. 1988. Field Guide to Nontidal Wetland Identification. Maryland Department of Natural Resources & U.S. Fish and Wildlife Service, Annapolis, Maryland and Newton Corner, Massachusetts. 283 pp.

____. 1991. The concept of a hydrophyte for wetland identification: individual plants adapt to wet environments. BioScience 41(4):236-247.

United States Department of Agriculture. 1971. Common Weeds of the United States. Dover Publications, New York. 463 pp.

Vogl, R.J. 1966. Salt-marsh vegetation of upper Newport Bay, California. Ecology 47(1):80-87.

Webb, J.W., Jr. 1982. Salt marshes of the Western Gulf of Mexico, pp. 89-109. In R.R. Lewis, III (Ed.), Creation and Restoration of Coastal Plant Communities. CRC Press, Boca Raton, Florida.

Whitlow, T.H. and R.W. Harris. 1979. Flood Tolerance in Plants: A State-of-the-Art Review. Technical Report E-79-2. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Woodhouse, W.W., Jr. and P.L. Knutson. 1982. Atlantic coastal marshes, pp. 45-70. In R.R. Lewis, III (Ed.), Creation and Restoration of Coastal Plant Communities. CRC Press, Boca Raton, Florida.

Zedler, J.B. 1984. Salt Marsh Restoration; A Guidebook for Southern California. California Sea Grant College Program, La Jolla, California. 46 pp.

Zedler, J.B., M. Josselyn, and C. Onuf. 1982. Restoration techniques, research, and monitoring: vegetation, pp. 63-74. In M. Josselyn (Ed.), Wetland Restoration and Enhancement in California. California Sea Grant College Program, La Jolla, California.

Zedler, P.H. 1987. The Ecology of Southern California Vernal Pools: A Community Profile. Biological Report 85(7.11). U.S. Fish and Wildlife Service, Washington, DC.

___. 1989. California's vernal pools. National Wetlands Newsletter May-June:2-5.

Zedler, P.H. and C. Black. 1988. Species preservation in artificially constructed habitats: preliminary evaluation based on a case study of vernal pools at Del Mar Mesa, San Diego County, pp. 367-372. In J.A. Kusler, S. Daly, and G. Brooks (Eds.), Proceedings of the National Wetland Symposium: Urban Wetlands. Association of Wetland Managers, Oakland, California.

Zieman, J.C., and R.T. Zieman. 1989. The ecology of the seagrass meadows of the west coast of Florida: a community profile. Biological Report 85(7.25). U.S. Fish and Wildlife Service, Washington, D.C. 155 pp.

Table G-1: Tidal Saltwater[1] (page 1 of 4)

Zone	Range of Zone[2]	Layer[3]	Species Name[4]		Salt Tolerance[5]
			Scientific	Common	
Above MHW	A	H	*Acorus calamus*	Sweet flag	Low
	A	H	*Arundo donax* *Invasive* Considered pest species in some states.	Giant reed	Low
	A	H	*Atriplex patula* (Annual)	Orache, Fat hen	High
	A	H	*Bacopa caroliniana*	Water hyssop	High
	A	H	*Batis maritima*	Saltwort	High
	A	H	*Borrichia frutescens*	Sea ox-eye	High
	A	H	*Carex lyngbyei*	Lyngbye's sedge	High (up to 20 ppt)
	A	H	*Carex obnupta*	Sough sedge, Pacific sedge	Low
	A	H	*Deschampsia cespitosa*	Tufted hairgrass	High (up to 20 ppt)
	A	H	*Distichlis spicata*	Salt grass, Spike grass, Alkali grass	High (up to 50 ppt)
	A and B	H	*Frankenia grandifolia*	Frankenia, Alkali heath	High
	A	H	*Jaumea carnosa*	Jaumea, Fleshy jaumea	High
	A	H	*Juncus balticus*	Baltic rush, Salt rush	Low
	A	H	*Juncus roemerianus*	Black needlerush	High
	A and B	H	*Monanthochloe littoralis*	Shoregrass, Salt cedar	High
	A and B	H	*Panicum virgatum*	Switchgrass	Low
	A	H	*Phragmites australis* *Invasive* Considered pest species in some states.	Wild reed, Common reed	High (up to 20 ppt)
	A	H	*Salicornia virginica*	Pickleweed, Pacific glasswort, Perennial pickleweed	High (up to 60 ppt)
	A	H	*Scirpus acutus*	Hardstem bulrush, Common tule	Low
	A	H	*Scirpus americanus* (Syn: S. olneyi)	Olney bulrush	Low
	A	H	*Scirpus maritimus*	Alkali bulrush, Salt-marsh bulrush	Low
	A	H	*Scirpus robustus*	Saltmeadow bulrush, Alkali bulrush	High (fluctuating, up to 25 ppt)
	A and B	H	*Sesuvium portulacastrum*	Sea purslane	Low
	A and B	H	*Spartina patens*	Saltmeadow cordgrass, Salt-marsh hay, Highwater grass	High
	A	H	*Spartina pectinata*	Prairie cordgrass	Low

Table G-1: Tidal Saltwater[1] (page 2 of 4)

Zone	Range of Zone[2]	Layer[3]	Species Name[4]		Salt Tolerance[5]
			Scientific	Common	
Above MHW	A	H	*Triglochin concinnum*	Arrowgrass	High
	A	H	*Triglochin maritimum*	Seaside arrowgrass	High
	A	H	*Typha angustifolia* *Invasive* Considered pest species in some states.	Narrow-leaved cattail	Low
	A and B	S	*Baccharis halimifolia*	Groundsel tree	High
	B	S	*Baccharis pilularis*	Coyote brush, Dwarf chaparrel-broom	High
	B	S	*Grindelia humilis*	Marsh gumplant, Marsh grindelia	Low
	A and B	S	*Iva frutescens*	Marsh elder	Low
	B	S	*Myrica cerifera*	Wax myrtle, Candleberry	Low
	A and B	S	*Myrica pensylvanica*	Bayberry	Low
	A	S	*Suaeda californica*	Sea blight	High
	to 1 ft. above MHW	T	*Avicennia germinans*	Black mangrove	High
	to 1 ft. above MHW	T	*Laguncularia racemosa*	White mangrove	High
Intertidal (MHW - MLW)	Upper 25%	H	*Batis maritima*	Saltwort	High
	Upper 50%	H	*Borrichia frutiscens*	Sea ox-eye	High
	Upper 50%	H	*Carex lyngbyei*	Lyngbye's sedge	High (up to 20 ppt)
	Upper 50%	H	*Carex obnupta*	Sough sedge, Pacific sedge	Low
	Upper 10%	H	*Deschampsia cespitosa*	Tufted hairgrass	High (up to 20 ppt)
	Upper 10%	H	*Jaumea carnosa*	Jaumea, Fleshy jaumea	High
	Upper 25%	H	*Juncus balticus*	Baltic rush, Salt rush	Low
	Upper 10%	H	*Juncus effusus*	Soft rush	Low
	Upper 50%	H	*Scirpus acutus*	Hardstem bulrush	Low
	Upper 50%	H	*Scirpus americanus* (Syn: S. olneyi)	Olney's bulrush	Low
	100%	H	*Scirpus californicus*	Southern bulrush	Low
	Upper 50%	H	*Scirpus pungens* (Syn: S. americanus)	Common three-square, Three-square rush, Swordgrass	Low
	Upper 50%	H	*Scirpus robustus* (may need influx of fresh water, especially in California)	Saltmeadow bulrush, Alkali bulrush	High (fluctuating, up to 25 ppt)

Table G-1: Tidal Saltwater[1] (page 3 of 4)

Zone	Range of Zone[2]	Layer[3]	Species Name[4]		Salt Tolerance[5]
			Scientific	Common	
Intertidal (MHW - MLW)	Mid 50%	H	*Scirpus validus*	Soft-stem bulrush	Low
	Upper 50%	H	*Spartina alterniflora*	Smooth cordgrass, Salt-marsh cordgrass	High
	Upper 50%	H	*Spartina foliosa*	Pacific cordgrass	High
	Upper 50%	H	*Spartina pectinata*	Prairie cordgrass	Low
	Upper 10%	H	*Triglochin maritimum*	Seaside arrowgrass	High
	Upper 20%	H	*Typha angustifolia* - *Invasive* Considered pest species in some states.	Narrow-leaved cattail	Low
	Upper 20%	S	*Hibiscus moscheutos*	Marsh hibiscus	Low
	Upper 20%	T	*Rhizophora mangle*	Red mangrove	High
Below MLW	Varies[6]	SAV	*Cymodocea filiformis* (Syn: Syringodium filiformis)	Manatee grass	High
			Elodea canadensis (Syn: Anacharis canadensis)	Waterweed	Low
			Halodule wrightii	Shoal grass	High
			Potamogeton pectinatus	Sago pond weed	Low
			Potamogeton perfoliatus	Redhead grass	Low
			Ruppia maritima	Widgeongrass, Ditch grass	High
			Thalassia testudinum	Turtle grass	High
			Zostera marina	Eelgrass	High

Table G-1: Tidal Saltwater[1] (page 4 of 4)

NOTE: The Research Team recommends that the use of invasive species usually should be avoided or minimized in wetland replacement. Some of the listed invasive species are on state noxious weed lists and therefore may be illegal to plant/propagate. They have been listed here to warn users of the manual that they are in fact considered invasive and can out-compete other wetland species rapidly to the point of dominating a wetland replacement project. Their use should be avoided.

1. All species vary in their location within a water regime, depending on the site location and/or water body (e.g., some water bodies are heavily influenced by wind or rain). Biological benchmarks should be measured for species, using plants found as close to the wetland creation site as possible. Refer to Chapter 2 of these Guidelines for a complete explanation of the use of biological benchmarks.

2. A - Often found throughout the spring tide zone
   Note: MHHW for plants on the west coast is not indicated in the tables. Plants that grow within the area between MHW and MHHW are listed as growing in Area A. Biological benchmark measurements are suggested for the establishment of the upper limit of growth for all species.

   B - Can tolerate upland conditions and often found in dune communities

3. SAV: Submerged aquatic vegetation
   FAV: Floating aquatic vegetation
   H: Herbaceous
   S: Shrub
   T: Tree

4. All species listed are perennials unless otherwise indicated.

5. Low salinity tolerance = at least 2 ppt but probably not greater than 10 ppt
   High salinity tolerance = at least 10 ppt but probably not greater than 33 ppt unless otherwise noted

6. The maximum depth at which submerged aquatic vegetation will grow depends strongly on water quality. Most SAV is extremely sensitive to turbid water, although species vary in tolerance.

Table G-2: Tidal Freshwater [1] (page 1 of 3)

Zone	Range of Zone[2]	Layer[3]	Species Name[4]	
			Scientific	Common
Above MHW	A	H	*Acorus calamus*	Sweet flag
	A	H	*Asclepias incarnata*	Swamp milkweed
	A	H	*Atriplex patula* (Annual)	Orache, Fat hen
	A	H	*Bacopa caroliniana*	Water hyssop
	A	H	*Carex lyngbyei*	Lyngbye's sedge
	A	H	*Carex obnupta*	Slough sedge, Pacific sedge
	A	H	*Deschampsia cespitosa*	Tufted hairgrass
	A	H	*Juncus balticus*	Baltic rush, Salt rush
	A	H	*Juncus effusus*	Soft rush
	A	H	*Juncus roemerianus*	Black needlerush
	A and B	H	*Panicum virgatum*	Switchgrass
	A	H	*Phragmites australis* *Invasive* Considered pest species in many states.	Wild reed, Common reed
	A and B	H	*Polygonum pensylvanicum* (Annual)	Pennsylvania smartweed, Pinkweed
	A	H	*Scirpus acutus*	Hardstem bulrush, Common tule
	A	H	*Scirpus americanus* (Syn: S. olneyi)	Olney bulrush
	A	H	*Scirpus maritimus*	Alkali bulrush, Salt-marsh bulrush
	A and B	H	*Sesuvium portulacastrum*	Sea purslane
	A	H	*Spartina cynosuroides*	Big cordgrass, Salt reed grass
	A	H	*Spartina pectinata*	Prairie cordgrass
	A	H	*Triglochin concinnum*	Arrowgrass
	A	H	*Triglochin maritimum*	Seaside arrowgrass
	A	H	*Typha angustifolia* *Invasive* Considered pest species in some states.	Narrow-leaved cattail
	A	H	*Typha latifolia* *Invasive* Considered pest species in some states.	Broad-leaved cattail
	A and B	S	*Alnus serrulata*	Hazel alder, Tag alder, Smooth alder
	A and B	S	*Baccharis halimifolia*	Groundsel tree
	A	S	*Cephalanthus occidentalis*	Buttonbush
	A and B	S	*Iva frutescens*	Marsh elder
	B	S	*Myrica cerifera*	Wax myrtle, Candleberry

Table G-2: Tidal Freshwater [1] (page 2 of 3)

Zone	Range of Zone[2]	Layer[3]	Species Name[4]	
			Scientific	Common
Above MHW	A and B	S	*Myrica pennsylvanica*	Bayberry
	B	S	*Rosa palustris*	Swamp rose
	B	T	*Alnus rubra* (Syn: A. oregona)	Red alder, Oregon alder
	A and B	T	*Fraxinus latifolia*	Oregon ash
	A and B	T	*Fraxinus pennsylvanica*	Green ash
	B	T	*Salix hookeriana*	Hooker willow, Coast willow
Intertidal (MHW - MLW)	Upper 50%	H	*Carex lyngbyei*	Lyngbye's sedge
	Upper 10%	H	*Deschampsia cespitosa*	Tufted hairgrass
	Upper 25%	H	*Juncus balticus*	Baltic rush, Salt rush
	Upper 10%	H	*Juncus effusus*	Soft rush
	Upper 10%	H	*Leersia oryzoides*	Rice cutgrass
	Upper 10%	H	*Lobelia cardinalis*	Cardinal flower
	Upper 50%	H	*Peltandra virginica*	Arrow arum, Tuckahoe, Wampee, Duck corn
	Upper 50%	H	*Pontedaria cordata*	Pickerel weed
	Mid 50%	H	*Sagittaria latifolia*	Duck potato, Arrowhead, Wapato
	Upper 50%	H	*Scirpus acutus*	Hardstem bulrush, Common tule
	Upper 50%	H	*Scirpus americanus* (Syn: S. olneyi)	Olney bulrush
	100%	H	*Scirpus californicus*	Southern bulrush
	Upper 50%	H	*Scirpus pungens* (Syn: S. americanus)	Common three-square, Three-square rush, Swordgrass, Chair-maker's rush
	Mid 50%	H	*Scirpus validus*	Soft-stem bulrush
		H	*Sium suave*	Water parsnip
	Upper 50%	H	*Spartina pectinata*	Prairie cordgrass
	Upper 10%	H	*Triglochin maritimum*	Seaside arrowgrass
	Upper 20%	H	*Typha angustifolia* *Invasive* Considered pest species in many states.	Narrow-leaved cattail
	Upper 20%	H	*Typha latifolia* *Invasive* Considered pest species in many states.	Broad-leaved cattail
	Mid 50%	H	*Zizania aquatica* (Annual)	Wild rice
	Upper 50%	H	*Zizaniopsis miliacea*	Southern cutgrass, Water millet, Giant cutgrass, Southern wild rice
	Upper 50%	S	*Cephalanthus occidentalis*	Buttonbush

Table G-2: Tidal Freshwater [1] (page 3 of 3)

Zone	Range of Zone[2]	Layer[3]	Species Name[4]	
			Scientific	Common
Intertidal	Upper 20%	S	*Hibiscus moscheutos*	Marsh hibiscus
Below MLW	Varies[5]	SAV	*Elodea canadensis* (Syn: Anacharis canadensis)	Waterweed
			Potamogeton diversifolius	Pond weed
			Potamogeton pectinatus	Sago pond weed
			Potamogeton perfoliatus	Redhead grass
			Ruppia maritima	Widgeongrass, Ditch grass
			Vallisneria americana	Wild celery, Tapegrass, Freshwater eelgrass
	Average: 1 - 3 ft.[6]	H	*Nuphar luteum*	Spatterdock, Yellow water lily, Cowlily
	Average: 0 - 1 ft.[6]	H	*Scirpus californicus*	Southern bulrush

NOTE: The Research Team recommends that the use of invasive species usually should be avoided or minimized in wetland replacement. Son of the listed invasive species are on state noxious weed lists and therefore may be illegal to plant/propagate. They have been listed here to wa users of the manual that they are in fact considered invasive and can out-compete other wetland species rapidly to the point of dominating wetland replacement project. Their use should be avoided.

1. All species vary in their location within a water regime, depending on the site location and/or water body (e.g., some water bodies are heavily influenced by wind or rain). Biological benchmarks should be measured for species, using plants found as close to the wetland creation site as possible. Refer to Chapter 2 of these Guidelines for an explanation of the use of biological benchmarks.

2. A - Often found throughout the spring tide area
   Note: MHHW for plants on the west coast is not indicated in the tables. Plants that grow within the area between MHW and MHHW are listed as growing in Area A. Biological benchmark measurements are suggested for the establishment of the upper limit of growth for all species.

   B - Can tolerate upland conditions and often found in dune communities

3. SAV: Submerged aquatic vegetation
   FAV: Floating aquatic vegetation
   H: Herbaceous
   S: Shrub
   T: Tree

4. All species listed are perennials unless otherwise indicated.

5. The maximum depth at which submerged aquatic vegetation will grow depends strongly on water quality. Most SAV is extremely sensitive to turbid water, although species vary in tolerance.

6. This plant grows well below mean low water at elevations where average tidal fluctuations result in the depths given.

Table G-3: Nontidal Freshwater: Semipermanently to Permanently Inundated or Saturated (page 1 of 5)

Depth Range [1, 2]	Layer[3]	Species Name[4]	
		Scientific	Common
N/A [5]	FAV	*Lemna minor*	Common duckweed
		Spirodela polyrhiza	Big duckweed
1 - x ft. * Depth depends strongly on water turbidity *	SAV	*Elodea canadensis* (Syn: *Anacharis canadensis*)	Waterweed
		Potamogeton diversifolius	Pond weed
		Potamogeton nodosus (Syn: *P. americanus*)	Longleaf pond plant
		Potamogeton pectinatus	Sago pond weed
		Potamogeton perfoliatus	Redhead grass
		Ruppia maritima	Widgeongrass, Ditch grass
		Vallisnerea americana	Wild celery, Tapegrass, Freshwater eelgrass
		Vallisneria spiralis	Wild celery
1 - 5 ft.	FAV	*Ceratophyllum demersum*	Coontail, Hornwort
		Nelumbo lutea	Lotus
1 - 3 ft.	FAV	*Nymphea odorata*	Fragrant water-lily, Pond-lily
	H	*Nuphar luteum*	Yellow water lily, Spatterdock, Cowlily
		Sagittaria rigida	Deep-water duck potato
2 in. - 1 ft.	FAV	*Nasturtium officianale*	True watercress
0 - 6 ft.	H	*Scirpus californicus*	Southern bulrush
0 - 5 ft.	H	*Scirpus acutus*	Hardstem bulrush, Common tule
0 - 3 ft.	H	*Cladium jamaicense*	Saw grass
		Polygonum amphibium	Water smartweed
		Polygonum punctatum	Dotted smartweed, Marsh smartweed, Red top
		Zizania aquatica (Annual)	Wild rice
	S	*Cephalanthus occidentalis*	Buttonbush
0 - 2 ft.	FAV	*Limnobium spongia*	Frog bit
	H	*Carex lacustris*	Lake sedge, Rip gut
		Phragmites australis *Invasive* Considered pest species in some states.	Wild reed, Common reed
		Sagittaria latifolia	Arrowhead, Duck potato, Wapato
		Sparganium emersum (Syn: *S. angustifolium*)	Narrow-leaved bur-reed

Table G-3: Nontidal Freshwater: Semipermanently to Permanently Inundated or Saturated (page 2 of 5)

Depth Range [1, 2]	Layer[3]	Species Name[4]	
		Scientific	Common
0 - 1 ft.	H	*Alisma plantago-aquatica*	Water plantain
		Bacopa caroliniana	Water hyssop
		Dulichium arundinaceum	Three-sided sedge
		Eleocharis equisetoides	Spike rush
		Eleocharis quadrangulata	Spike rush
		Glyceria grandis	Reed meadow grass
		Glyceria septentrionalis	Manna grass, Floating manna, Sweet grass
		Hydrocotyle umbellata	Water-pennywort
		Juncus effusus	Soft rush
		Panicum hemitomon	Maidencane
		Peltandra virginica	Arrow arum, Tuckahoe, Wampee, Duck corn
		Phalaris arundinacea *Invasive* Considered pest species in many states.	Reed canary grass
		Polygonum hydropiperoides	Marsh smartweed
		Pontederia cordata	Pickerel weed
		Sagittaria graminae	Grass-like duck potato
		Sagittaria platyphylla (Syn: *S. graminae var. platyphylla*)	Delta duck potato
		Saururus cernuus	Lizardtail, Water dragon, Swamplily
		Scirpus pungens (Syn: *S. americanus*)	Common three-square, Three-square rush, Swordgrass, Chair-maker's rush
		Scirpus validus	Soft stem bulrush
		Sparganium eurycarpum	Giant bur-reed, Great bur-reed
		Triglochin maritimum	Seaside arrowgrass
		Typha angustifolia *Invasive* Considered pest species in many states.	Narrow-leaved cattail
		Typha latifolia *Invasive* Considered pest species in many states.	Broad-leaved cattail
		Zizaniopsis miliacea	Southern cutgrass, Water millet, Giant cutgrass, Southern wildrice

Table G-3: Nontidal Freshwater: Semipermanently to Permanently Inundated or Saturated (page 3 of 5)

Depth Range[1, 2]	Layer[3]	Species Name[4]	
		Scientific	Common
0 - 0.5 ft.	H	*Acorus calamus*	Sweet flag
		Caltha palustris	Marsh marigold, Cowslip, King-cup
		Carex aperta	Columbia sedge
		Carex aquatilis	Water sedge
		Carex comosa	Bottlebrush sedge
		Carex hystricina	Porcupine sedge
		Carex retrorsa	Retrorse sedge
		Carex rostrata	Beaked sedge
		Carex stricta	Tussock sedge
		Deschampsia cespitosa	Tufted hairgrass
		Eleocharis obtusa (Annual; Syn: *E. ovata*)	Blunt spike rush
		Iris pseudacorus	Yellow water iris
		Iris versicolor	Blue flag, Poison flag, Clajeux
		Juncus balticus	Baltic rush, Salt rush
		Lysichiton americanum	Yellow skunk cabbage
		Lythrum salicaria *Invasive* Considered pest species in many states.	Purple loosestrife, Spiked lythrum, Salicaire or Bouquet violet
		Polygonum pensylvanicum (Annual)	Pennsylvania smartweed, Pinkweed
		Rumex verticillatus	Water dock, Swamp dock
		Scirpus americanus (Syn: *S. olneyi*)	Olney bulrush
		Scirpus fluviatilis	River bulrush
		Scirpus microcarpus	Small fruited bulrush
		Sium suave	Water parsnip
		Sparganium americanum	Eastern bur-reed, Lesser bur-reed
		Spartina pectinata	Prairie cordgrass
	S	*Itea virginica*	Tassel-white, Virginia sweetspire
		Spiraea douglasii	Douglas' spirea
0 - 0.25 ft.	H	*Leersia oryzoides*	Rice cutgrass
Saturated Soil (Water to Surface)	H	*Eleocharis palustris*	Spikerush
		Juncus ensifolius	Swordleaf rush, Three-stamened rush
		Lobelia cardinalis	Cardinal flower

Table G-3: Nontidal Freshwater: Semipermanently to Permanently Inundated or Saturated (page 4 of 5)

Depth Range [1, 2]	Layer[3]	Species Name[4]	
		Scientific	Common
Saturated Soil (Water to Surface)	H	*Onoclea sensibilis*	Sensitive fern
		Osmunda cinnamomea	Cinnamon fern, Buckhorn, Fiddle-heads
		Osmunda regalis	Royal fern, Flowering fern
		Symplocarpus foetidus	Skunk cabbage
		Thelypteris noveboracensis	New York fern
		Thelypteris palustris	Marsh fern, Meadow fern, Snuffbox fern
		Woodwardia areolata	Netted chain fern
Riparian Water Regime [6]	T	*Acer macrophyllum*	Big-leaf maple
		Alnus rhombifolia [7]	White alder
		Chamaecyparis thyoides	Atlantic white cedar, False cypress, Swamp-cedar, Southern white cedar
		Fraxinus latifolia	Oregon ash
		Platanus racemosa	California sycamore
		Populus balsimifera (Syn: *P. trichocarpa*)	Black cottonwood
		Populus fremontii	Fremont cottonwood
		Salix boothii (Syn: *S. pseudocordata*)	Firm leaf willow
		Salix gooddingii	Goodding's willow
		Salix hindsiana (Syn: *S. sessifolia*)	Sandbar willow, Hinds willow
		Salix laevigata [7] (Syn: *S. bonplandiana*)	Red willow
		Salix lasiandra (Syn: *S. caudata*)	Yellow willow, Pacific willow
		Salix lasiolepis	Arroyo willow, White willow
		Salix lutea	Shining willow
		Salix purpurea	Basket willow, Streamco willow, Purple osier
		Taxodium ascendens (Syn: *T. distichum var. nutans*)	Pond cypress
		Taxodium distichum	Bald cypress

Table G-3: Nontidal Freshwater: Semipermanently to Permanently Inundated or Saturated (page 5 of 5)

NOTE: The Research Team recommends that the use of invasive species usually should be avoided or minimized in wetland replacement. Some of the listed invasive species are on state noxious weed lists and therefore may be illegal to plant/propagate. They have been listed here to warn users of the manual that they are in fact considered invasive and can out-compete other wetland species rapidly to the point of dominating a wetland replacement project. Their use should be avoided.

1. Depth tolerances are intended to be guides for choosing vegetation for planned water regimes. Some species may have slightly different tolerances due to the occurrence of local varieties or special conditions. The best way to avoid mortality resulting from these factors is to use biological benchmarks as guides for elevations at which to plant new vegetation. Refer to Chapter 2 in these Guidelines for a complete explanation on the use of biological benchmarks.

2. Plants identified as tolerating depths over one foot may develop differently, depending on whether they germinate and grow in high or in low water conditions. Certain morphological adaptations to deeper water, such as longer stems, may not develop if they are not grown in a depth similar to that into which they will be transplanted. This should be a significant consideration when obtaining plant material. If it is not possible to have similar growing conditions for plants to be placed in depths over one foot, then dormant stock should be planted so that plants will develop the morphological structures necessary to tolerate deeper water.

3. SAV: Submerged aquatic vegetation
   FAV: Floating aquatic vegetation
   H: Herbaceous
   S: Shrub
   T: Tree

4. All species listed are perennials unless otherwise indicated.

5. These floating aquatic plants are not rooted in soil; therefore, their survival is controlled by factors other than depth, such as turbulence of water surface, etc.

6. The "riparian water regime" is one found in the riparian zone of a river, stream, or other body of water, which is defined by Mitch and Gosselink (1986) as "the land adjacent to that body of water that is, at least periodically, influenced by flooding." For the purposes of this appendix, woody, non-riparian species requiring similar hydrology are not listed separately in the tables. For riparian woody species, depth of flooding is not as important as the duration of ground saturation above the level of the roots. Tolerance of duration is implied in the definition of the hydroperiod (e.g., Permanent). Some riparian species which grow in arid regions may only require a permanent groundwater supply.

7. These riparian, woody species have been identified as ones requiring swiftly moving water for survival (Faber, Keller, et al., 1989). Other riparian species may be sensitive to standing water, especially as seedlings (John Rieger, personal communication).

Table G-4: Nontidal Freshwater: Regularly Inundated or Saturated (page 1 of 6)

Depth Range [1, 2]	Layer[3]	Species Name[4]	
		Scientific	Common
1 - x ft.	SAV	*Potamogeton nodosus* (Syn: *P. americanus*) *Depth depends strongly on turbidity*	Longleaf pond plant
1 - 5 ft.	FAV	*Ceratophyllum demersum*	Coontail, Hornwort
1 - 3 ft.	H	*Nuphar luteum*	Yellow water lily, Spatterdock, Cowlily
		Sagittaria rigida	Deep-water duck potato
0 - 6 ft.	H	*Scirpus californicus*	Southern bulrush
0 - 5 ft.	H	*Scirpus acutus*	Hardstem bulrush, Common tule
0 - 3 ft.	H	*Cladium jamaicense*	Saw grass
		Polygonum amphibium	Water smartweed
		Polygonum punctatum	Dotted smartweed, Marsh smartweed, Red top
		Zizania aquatica (Annual)	Wildrice
	S	*Cephalanthus occidentalis*	Buttonbush
0 - 2 ft.	FAV	*Limnobium spongia*	Frog bit
	H	*Carex lacustris*	Lake sedge, Rip gut
		Phragmites australis *Invasive* Considered pest species in many states.	Wild reed, Common reed
		Sagittaria latifolia	Arrowhead, Duck potato, Wapato
		Sparganium emersum (Syn: *S. angustifolium*)	Narrow-leaved bur-reed
0 - 1 ft.	H	*Alisma plantago-aquatica*	Water plantain
		Bacopa caroliniana	Water hyssop
		Cyperus esculentus	Chufa, Ground almond, Yellow nutgrass, Yellow nutsedge
		Dulichium arundinaceum	Three-sided sedge
		Eleocharis equisetoides	Spike rush
		Eleocharis quadrangulata	Spike rush
		Glyceria grandis	Reed meadow grass
		Glyceria septentrionalis	Manna grass, Floating manna, Sweet grass
		Hydrocotyle umbellata	Water-pennywort
		Juncus effusus	Soft rush
		Panicum hemitomon	Maidencane
		Peltandra virginica	Arrow arum, Tuckahoe, Wampee, Duck corn

Table G-4: Nontidal Freshwater: Regularly Inundated or Saturated (page 2 of 6)

Depth Range[1, 2]	Layer[3]	Species Name[4]	
		Scientific	Common
0 - 1 ft.	H	*Phalaris arundinacea* *Invasive* Considered pest species in many states.	Reed canary grass
		Polygonum hydropiperoides	Marsh smartweed
		Polygonum persicaria (Annual)	Ladysthumb, Heart's-ease
		Pontederia cordata	Pickerel weed
		Sagittaria graminae	Grass-like duck potato
		Sagittaria platyphylla (Syn: *S. graminae var. platyphylla*)	Delta duck potato
		Saururus cernuus	Lizardtail, Water dragon, Swamplily
		Scirpus maritimus	Alkali bulrush, Salt-marsh bulrush
		Scirpus pungens (Syn: *S. americanus*)	Common three-square, Three-square rush, Swordgrass, Chair-maker's rush
		Scirpus validus	Soft stem bulrush
		Sparganium americanum	Eastern bur-reed, Lesser bur-reed
		Sparganium eurycarpum	Giant bur-reed, Great bur-reed
		Triglochin maritimum	Seaside arrowgrass
		Typha angustifolia *Invasive* Considered pest species in many states.	Narrow-leaved cattail
		Typha latifolia *Invasive* Considered pest species in many states.	Broad-leaved cattail
		Zizaniopsis miliacea	Southern cutgrass, Water millet, Giant cutgrass, Southern wildrice
0 - 0.5 ft.	H	*Acorus calamus*	Sweet flag
		Calamagrostis canadensis	Reed grass
		Caltha palustris	Marsh marigold, Cowslip, King-cup
		Carex aperta	Columbia sedge
		Carex aquatilis	Water sedge
		Carex comosa	Bottlebrush sedge
		Carex hystricina	Porcupine sedge
		Carex lanuginosa	Wooly sedge
		Carex lenticularis	Kellogg sedge
		Carex retrorsa	Retrorse sedge
		Carex rostrata	Beaked sedge

Table G-4: Nontidal Freshwater: Regularly Inundated or Saturated (page 3 of 6)

Depth Range [1, 2]	Layer[3]	Species Name[4]	
		Scientific	Common
0 - 0.5 ft.	H	*Carex stricta*	Tussock sedge
		Carex vulpinoidea	Fox sedge
		Deschampsia cespitosa	Tufted hairgrass
		Eleocharis obtusa (Annual; Syn: *E. ovata*)	Blunt spike rush
		Iris pseudacorus	Yellow water iris
		Iris versicolor	Blue flag
		Juncus balticus	Baltic rush, Salt rush
		Leersia oryzoides	Rice cutgrass
		Lysichiton americanum	Yellow skunk cabbage
		Lythrum salicaria *Invasive* Considered pest species in many states.	Purple loosestrife, Spiked lythrum, Salicaire or Bouquet violet
		Polygonum pensylvanicum (Annual)	Pennsylvania smartweed, Pinkweed
		Rumex verticillatus	Water dock, Swamp dock
		Scirpus americanus (Syn: *S. olneyi*)	Olney bulrush
		Scirpus fluviatilis	River bulrush
		Scirpus microcarpus	Small fruited bulrush
		Sium suave	Water parsnip
		Spartina pectinata	Prairie cordgrass
	S	*Baccharis halimifolia*	Groundsel tree
		Itea virginica	Tassel-white, Virginia sweetspire
		Spiraea douglasii	Douglas' spirea
0 - 0.25 ft.	S	*Alnus serrulata*	Hazel alder, Tag alder, Smooth alder
		Hibiscus moscheutos	Marsh hibiscus
Saturated Soil (Water to Surface)	H	*Asclepias incarnata*	Swamp milkweed
		Eleocharis palustris	Spikerush
		Juncus ensifolius	Swordleaf rush, Three-stamened rush
		Lobelia cardinalis	Cardinal flower
		Onoclea sensibilis	Sensitive fern
		Osmunda cinnamomea	Cinnamon fern, Buckhorn fern, Fiddle-heads
		Osmunda regalis	Royal fern, Flowering fern
		Symplocarpus foetidus	Skunk cabbage

Table G-4: Nontidal Freshwater: Regularly Inundated or Saturated (page 4 of 6)

Depth Range [1, 2]	Layer[3]	Species Name[4]	
		Scientific	Common
Saturated Soil (Water to Surface)	H	*Thelypteris noveboracensis*	New York fern
		Thelypteris palustris	Marsh fern, Meadow fern, Snuffbox fern
		Woodwardia areolata	Netted chain fern
	S	*Myrica cerifera*	Wax myrtle, Candleberry
		Rosa palustris	Swamp rose
	T	*Thuja plicata*	Western red cedar, Giant arborvitae, Canoe cedar, Pacific red cedar, Shinglewood
Riparian Water Regime [5]	S	*Baccharis glutinosa*	Mule fat, Water-wally, Seep-willow
		Clethra alnifolia	Sweet pepperbush
		Ilex cassine	Dahoon holly, Cassena holly, Henderson-wood
		Leucothoe racemosa	Fetterbush
		Rosa californica	Wild rose
		Rubus ursinus (Syn: *R. vitifolius*)	California blackberry
	T	*Acer macrophyllum*	Big-leaf maple
		Acer negundo	Box elder, Ash-leaved maple
		Alnus rhombifolia [6]	White alder
		Betula populifolia	Gray birch, White birch, Fire birch, Oldfield birch
		Chamaecyparis thyoides	Atlantic white cedar, False cypress, Swamp cedar, Southern white cedar
		Fraxinus latifolia	Oregon ash
		Fraxinus pennsylvanica	Green ash
		Gleditsia aquatica	Water locust
		Gordonia lasianthus	Loblolly bay
		Liquidambar styraciflua	Sweetgum
		Nyssa aquatica	Water tupelo
		Pinus elliotti	Slash pine
		Pinus serotina	Pond pine, Pocosin pine, Marsh pine
		Pinus taeda	Loblolly pine
		Platanus racemosa	California sycamore
		Populus balsimifera (Syn: *P. trichocarpa*)	Black cottonwood
		Populus fremontii	Fremont cottonwood

Table G-4: Nontidal Freshwater: Regularly Inundated or Saturated (page 5 of 6)

Depth Range [1, 2]	Layer[3]	Species Name[4]	
		Scientific	Common
Riparian Water Regime [5]	T	*Salix boothii* (Syn: *S. pseudocordata*)	Firm leaf willow
		Salix drummondiana	Drummond willow
		Salix exigua	Sandbar willow
		Salix goodingii	Goodding's willow
		Salix hindsiana (Syn: *S. sessifolia*)	Sandbar willow, Hinds willow
		Salix laevigata [6] (Syn: *S. bonplandiana*)	Red willow
		Salix lasiandra (Syn: *S. caudata*)	Yellow willow, Pacific willow
		Salix lasiolepis/Salix alba	Arroyo willow/White willow
		Salix lutea	Shining willow
		Salix nigra	Black willow
		Salix purpurea	Basket willow, Streamco willow, Purple osier
		Taxodium ascendens (Syn: *T. distichum var. nutans*)	Pond cypress
		Taxodium distichum	Bald cypress
		Thuja occidentalis	Northern white cedar, Arbor vitae

Table G-4: Nontidal Freshwater: Regularly Inundated or Saturated (page 6 of 6)

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1. Depth tolerances are intended to be guides for choosing vegetation for planned water regimes. Some species may have slightly different tolerances due to the occurrence of local varieties or special conditions. The best way to avoid mortality resulting from these factors is to use biological benchmarks as guides for elevations at which to plant new vegetation. Refer to Chapter 2 in these Guidelines for a complete explanation on the use of biological benchmarks.

2. Plants identified as tolerating depths over one foot may develop differently, depending on whether they germinate and grow in high or low water conditions. Certain morphological adaptations may not develop if plants are not grown in a depth similar to that into which they will be transplanted. This should be a significant consideration when obtaining plant material. If it is not possible to have similar growing conditions for plants to be placed in depths over one foot, then dormant stock should be planted so that plants will develop the morphological structures necessary to tolerate deeper water.

3. SAV: Submerged aquatic vegetation
   FAV: Floating aquatic vegetation
   H: Herbaceous
   S: Shrub
   T: Tree

4. All species listed are perennials unless otherwise indicated.

5. The "riparian water regime" is one found in the riparian zone of a river, stream, or other body of water, which is defined by Mitch and Gosselink (1986) as "the land adjacent to that body of water that is, at least periodically, influenced by flooding." For the purposes of this appendix, woody, non-riparian species requiring similar hydrology are not listed separately in the tables. For riparian woody species, depth of flooding is not as important as the duration of ground saturation above the level of the roots. Tolerance of duration is implied in the definition of the hydroperiod (e.g., Regular). Some riparian species which grow in arid regions may only require a regular groundwater supply.

6. These riparian, woody species have been identified as ones requiring swiftly moving water for survival (Faber, Keller, et al., 1989). Other riparian species may be sensitive to standing water, especially as seedlings (John Rieger, personal communication).

Table G-5: Nontidal Freshwater: Seasonally Inundated or Saturated[1] (page 1 of 5)

Includes Drought-Tolerant Species

Layer[2]	Species Name[3]	
	Scientific	Common
H	*Agrostis alba*	Redtop
	Andropogon glomeratus	Lowland broom sedge, Bushy beardgrass
	Arisaema triphyllum	Small Jack-in-the-pulpit
	Asclepias incarnata	Swamp milkweed
	Aster novae-angliae	New England aster
	Calamagrostis canadensis	Reed grass
	Caltha palustris	Marsh marigold, Cowslip, King-cup
	Carex aperta	Columbia sedge
	Carex aquatilis	Water sedge
	Carex comosa	Bottlebrush sedge
	Carex hystricina	Porcupine sedge
	Carex lacustris	Lake sedge, Rip gut
	Carex lanuginosa	Wooly sedge
	Carex lenticularis	Kellogg sedge
	Carex retrorsa	Retrorse sedge
	Carex rostrata	Beaked sedge
	Carex stipata	Awl-fruited sedge
	Carex stricta	Tussock sedge
	Carex trichocarpa	Slough sedge
	Carex vulpinoidea	Fox sedge
	Cladium jamaicense	Saw grass
	Cyperus esculentus	Chufa, Ground almond, Yellow nutgrass, Yellow nutsedge
	Eleocharis palustris	Spikerush
	Juncus balticus	Baltic rush, Salt rush
	Juncus ensifolius	Swordleaf rush, Three-stamened rush
	Juncus tenuis	Slender rush
	Juncus torreyi	Torrey rush
	Leersia oryzoides	Rice cutgrass
	Lysichiton americanum	Yellow skunk cabbage
	Lythrum salicaria *Invasive* Considered pest species in many states.	Purple loosestrife, Spiked lythrum, Salicaire or Bouquet violet

Table G-5: Nontidal Freshwater: Seasonally Inundated or Saturated[1] (page 2 of 5)

Includes Drought-Tolerant Species

Layer[2]	Species Name[3]	
	Scientific	Common
H	*Onoclea sensibilis*	Sensitive fern
	Osmunda cinnamomea	Cinnamon fern, Buckhorn fern, Fiddle-heads
	Osmunda regalis	Royal fern, Flowering fern
	Panicum virgatum	Switchgrass
	Phalaris arundinacea *Invasive* Considered pest species in many states.	Reed canary grass
	Phragmites australis *Invasive* Considered pest species in many states.	Common reed, Wild reed
	Polygonum persicaria (Annual)	Ladysthumb, Heart's-ease
	Scirpus cyperinus	Wool grass
	Scirpus microcarpus	Small fruited bulrush
	Scirpus pungens (Syn: *S. americanus*)	Common three-square, Three-square rush, Swordgrass, Chair-maker's rush
	Sparganium emersum (Syn: *S. angustifolium*)	Narrow-leaved bur-reed
	Symplocarpus foetidus	Skunk cabbage
	Thelypteris noveboracensis	New York fern
	Thelypteris palustris	Marsh fern, Meadow fern, Snuffbox fern
	Typha angustifolia *Invasive* Considered pest species in many states.	Narrow-leaved cattail
	Typha latifolia *Invasive* Considered pest species in many states.	Broad-leaved cattail
	Woodwardia areolata	Netted chain fern
S	*Alnus serrulata*	Hazel alder, Tag alder, Smooth alder
	Amorpha fruticosa	False indigo bush, Indigo bush
	Aronia arbutifolia (Syn: *Pyrus arbutifolia*)	Red chokeberry
	Baccharis glutinosa	Mule fat, Water-wally, Seep-willow
	Baccharis halimifolia	Groundsel tree
	Celtis occidentalis	Hackberry, Sugarberry
	Cephalanthus occidentalis	Buttonbush
	Clethra alnifolia	Sweet pepperbush
	Forestiera acuminata	Swamp-privet
	Hibiscus moscheutos	Marsh hibiscus
	Ilex cassine	Dahoon holly, Cassena holly, Henderson-wood

Table G-5: Nontidal Freshwater: Seasonally Inundated or Saturated[1] (page 3 of 5)
Includes Drought-Tolerant Species

Layer[2]	Species Name[3]	
	Scientific	Common
S	*Ilex decidua*	Possumhaw, Deciduous holly
	Ilex glabra	Bitter gallberry, Inkberry
	Ilex verticillata	Winterberry
	Itea virginica	Tassel-white, Virginia sweetspire
	Leucothoe racemosa	Fetterbush
	Lindera benzoin (Syn: *Benzoin aestivale*)	Common spicebush
	Magnolia virginiana	Sweetbay magnolia
	Myrica pensylvanica	Bayberry
	Rosa californica	Wild rose
	Rosa palustris	Swamp rose
	Rubus spectabilis	Salmonberry
	Rubus ursinus (Syn: *vitifolius*)	California blackberry
	Sambucus canadensis	Elderberry, American elder
	Spiraea douglasii	Douglas' spirea
	Vaccinium corymbosom	Highbush blueberry
	Viburnum dentatum	Southern arrowwood
	Viburnum lentago	Nannyberry
	Viburnum trilobum	Highbush cranberry, American cranberrybush
T	*Acer floridanum*	Florida maple
	Acer negundo	Box elder, Ash-leaved maple
	Acer rubrum	Red maple
	Acer saccharinum	Silver maple, White maple, Soft maple, River maple
	Alnus rubra (Syn: *A. oregona*)	Red alder, Oregon alder
	Amelanchier canadensis	Serviceberry, Shadbush
	Betula nigra	River birch
	Betula populifolia	Gray birch, White birch, Fire birch, Oldfield birch
	Carya aquatica	Water hickory
	Chamaecyparis thyoides	Atlantic white cedar, False cypress, Swamp-cedar, Southern white cedar
	Cornus amomum	Silky dogwood
	Cornus foemina racemosa (Syn: *C. racemosa*)	Graystem dogwood

Table G-5: Nontidal Freshwater: Seasonally Inundated or Saturated[1]
Includes Drought-Tolerant Species

Layer[2]	Species Name[3]	
	Scientific	Common
T	*Cornus sericea* (Syn: *C. stolonifera*)	Red-osier dogwood
	Fraxinus caroliniana	Carolina ash
	Fraxinus latifolia	Oregon ash
	Fraxinus nigra	Black ash
	Fraxinus pennsylvanica	Green ash
	Gleditsia aquatica	Water locust
	Gordonia lasianthus	Loblolly bay
	Liquidambar styraciflua	Sweetgum
	Nyssa aquatica	Water tupelo
	Nyssa sylvatica	Black gum, Black tupelo, Sour gum
	Persea barbonia (Syn: *P. palustris*)	Redbay, Swamp bay
	Picea sitchensis	Sitka spruce
	Pinus elliotti	Slash pine
	Pinus rigida	Pitch pine
	Pinus serotina	Pond pine, Pocosin pine , Marsh pine
	Pinus taeda	Loblolly pine
	Platanus occidentalis	Sycamore, Buttonwood, Planetree
	Platanus racemosa	California sycamore
	Populus deltoides	Eastern cottonwood
	Quercus bicolor	Swamp white oak
	Quercus lyrata	Overcup oak, Swamp post oak, Swamp white oak, Water white oak
	Quercus nigra	Water oak, Possum oak
	Quercus nuttallii	Nuttall's oak, Red river oak, Striped oak
	Quercus palustris	Pin oak, Spanish oak
	Quercus phellos	Willow oak
	Salix drummondiana	Drummond willow
	Salix exigua	Sandbar willow
	Salix hookeriana	Hooker willow, Coast willow
	Salix lasiolepis/Salix alba	Arroyo willow/White willow
	Salix nigra	Black willow

Table G-5: Nontidal Freshwater: Seasonally Inundated or Saturated[1] (page 5 of 5)

Includes Drought-Tolerant Species

Layer[2]	Species Name[3]	
	Scientific	Common
T	*Taxodium ascendens* (Syn: *T. distichum var. nutans*)	Pond cypress
	Taxodium distichum	Bald cypress
	Thuja occidentalis	Northern white cedar, Arbor vitae
	Thuja plicata	Western redcedar, Giant arborvitae, Canoe cedar, Pacific redcedar, Shinglewood
	Ulmus americana	American elm, White elm

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1. The use of biological benchmarks is the best method to determine correct plant elevations in a seasonally flooded area. Refer to Chapter 2 in these Guidelines for a complete explanation of the use of biological benchmarks. Fluctuating water levels and duration of flooding throughout the growing season have a greater effect on the success of species than depth of flooding.

2. H: Herbaceous vegetation
   S: Shrub
   T: Tree

3. All species listed are perennials unless otherwise indicated.

Table G-6: Nontidal Freshwater: Irregularly Inundated or Saturated[1] (page 1 of 3)

Includes Drought-Tolerant Species

Layer[2]	Species Name[3]	
	Scientific	Common
H	*Agrostis alba*	Redtop
	Andropogon glomeratus	Lowland broom sedge, Bushy beardgrass
	Andropogon virginicus	Broom sedge
	Arisaema triphyllum	Small Jack-in-the-pulpit
	Asclepias incarnata	Swamp milkweed
	Aster novae-angliae	New England aster
	Carex aperta	Columbia sedge
	Carex lanuginosa	Wooly sedge
	Carex lenticularis	Kellogg sedge
	Carex retrorsa	Retrorse sedge
	Carex stipata	Awl-fruited sedge
	Carex trichocarpa	Slough sedge
	Cyperus esculentus	Chufa, Ground almond, Yellow nutgrass, Yellow nutsedge
	Juncus ensifolius	Swordleaf rush, Three-stamened rush
	Juncus tenuis	Slender rush
	Juncus torreyi	Torrey rush
	Leersia oryzoides	Rice cutgrass
	Lythrum salicaria *Invasive* Considered pest species in many states.	Purple loosestrife, Spiked lythrum, Salicaire or Bouquet violet
	Onoclea sensibilis	Sensitive fern
	Osmunda cinnamomea	Cinnamon fern, Buckhorn fern, Fiddle-heads
	Osmunda regalis	Royal fern, Flowering fern
	Panicum virgatum	Switchgrass
	Scirpus cyperinus	Wool grass
	Thelypteris noveboracensis	New York fern
	Thelypteris palustris	Marsh fern, Meadow fern, Snuffbox fern
	Typha angustifolia *Invasive* Considered pest species in many states.	Narrow-leaved cattail
	Typha latifolia *Invasive* Considered pest species in many states.	Broad-leaved cattail
	Woodwardia areolata	Netted chain fern

Table G-6: Nontidal Freshwater: Irregularly Inundated or Saturated[1] (page 2 of 3)
Includes Drought-Tolerant Species

Layer[2]	Species Name[3]	
	Scientific	Common
S	*Amorpha fruticosa*	False indigo bush, Indigo bush
	Aronia arbutifolia (Syn: *Pyrus arbutifolia*)	Red chokeberry
	Baccharis glutinosa	Mule fat, Water-wally, Seep-willow
	Celtis occidentalis	Hackberry, Sugarberry
	Cephalanthus occidentalis	Buttonbush
	Forestiera acuminata	Swamp-privet
	Hibiscus moscheutos	Marsh hibiscus
	Ilex decidua	Possumhaw, Deciduous holly
	Ilex verticillata	Winterberry
	Magnolia virginiana	Sweetbay magnolia
	Myrica pensylvanica	Bayberry
	Rosa californica	Wild rose
	Rosa palustris	Swamp rose
	Rubus spectabilis	Salmonberry
	Rubus ursinus (Syn: *R. vitifolius*)	California blackberry
	Sambucus canadensis	Elderberry, American elder
	Spiraea douglasii	Douglas' spirea
T	*Acer floridanum*	Florida maple
	Acer negundo	Box elder, Ash-leaved maple
	Acer rubrum	Red maple
	Acer saccharinum	Silver maple, White maple, Soft maple, River maple
	Alnus rubra (Syn: *A. oregona*)	Red alder, Oregon alder
	Amelanchier canadensis	Serviceberry, Shadbush
	Betula nigra	River birch
	Betula populifolia	Gray birch, White birch, Fire birch, Oldfield birch
	Carya aquatica	Water hickory
	Chamaecyparis thyoides	Atlantic white cedar, False cypress, Swamp-cedar, Southern white cedar
	Cornus amomum	Silky dogwood
	Cornus foemina racemosa (Syn: *C. racemosa*)	Graystem dogwood
	Cornus sericea (Syn: *C. stolonifera*)	Red-osier dogwood

Table G-6: Nontidal Freshwater: Irregularly Inundated or Saturated[1] (page 3 of 3)

Includes Drought-Tolerant Species

Layer[2]	Species Name[3]	
	Scientific	Common
T	*Fraxinus caroliniana*	Carolina ash
	Fraxinus latifolia	Oregon ash
	Fraxinus nigra	Black ash
	Fraxinus pennsylvanica	Green ash
	Gleditsia aquatica	Water locust
	Gordonia lasianthus	Loblolly bay
	Liquidambar styraciflua	Sweetgum
	Nyssa aquatica	Water tupelo
	Nyssa sylvatica	Black gum, Black tupelo, Sour gum
	Persea barbonia (Syn: *P. palustris*)	Redbay, Swamp bay
	Pinus rigida	Pitch pine
	Pinus taeda	Loblolly pine
	Platanus occidentalis	Sycamore, Buttonwood, Planetree
	Quercus bicolor	Swamp white oak
	Quercus lyrata	Overcup oak, Swamp post oak, Swamp white oak, Water white oak
	Quercus palustris	Pin oak, Spanish oak
	Quercus phellos	Willow oak
	Salix lasiolepis/Salix alba	Arroyo willow / White willow
	Salix nigra	Black willow
	Taxodium ascendens (Syn: *T. distichum var. nutans*)	Pond cypress
	Taxodium distichum	Bald cypress
	Ulmus americana	American elm, White elm

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1. The use of biological benchmarks is the best method to determine correct plant elevations in an irregularly flooded area. Refer to Chapter 2 of these Guidelines for a complete explanation of the use of biological benchmarks. Fluctuating water levels and duration of flooding throughout the growing season have a greater effect on the success of species than depth of flooding.

2. H: Herbaceous vegetation
   S: Shrub
   T: Tree

3. All species listed are perennials unless otherwise indicated.

Table G-7: Species Range[1] (page 1 of 11)

Species Name (National Range of Indicator Status)	Range	Hardiness Zone [2]
Acer floridanum (not listed)	VA & se MO s to FL & TX	6b
Acer macrophyllum (FACU, FAC)	West Coast: B.C. to s CA	4a
Acer negundo (FAC, FACW)	NH & VT to s Ont., MT, & WY, s to FL & TX	4a
Acer rubrum (FACW, OBL)	Que. to Man., s to s FL, OK, and TX	2b
Acer saccharinum (FAC, FACW)	N.B. - Ont. & MN, SD, s to FL, OK, LA	2b
Acorus calamus (OBL)	P.E.I. to MT & OR, s to N.S., FL, TX, & CO	4b
Agrostis alba (FACW, OBL)	** Varieties exist ** Nfld. to Yuk., s to GA, LA, NM, AZ, and CA	2a
Alisma plantago-aquatica (OBL)	N.S. & Que. to B.C., s to FL, TX, & Mex.	4b
Alnus rhombifolia (FACW)	Western mountains from sw B.C. to s CA	6a
Alnus rubra (FAC, FACW) (Syn: *A. oregona*)	n coastal CA, n to AK	4a
Alnus serrulata (FACW+, OBL)	N.S., s to nw FL, w to IL & OK	5a
Amelanchier canadensis (FACU, FAC)	Nfld. to MS on coastal plain	4b
Amorpha fruticosa (FAC, OBL)	** Varieties exist ** N.E. to MN & Sask, s to FL & TX	5a
Andropogon glomeratus (FACW, OBL)	ME to OH, s to FL & TX	7a
Andropogon virginicus (not listed)	MA & NY to OH, IN, s IL, MO, KS, s to FL & TX	5b
Arisaema triphyllum (FAC, FACW)	N.S. & N.B. to MN s to FL & TX	4a
Aronia arbutifolia (FACW) (Syn: *Pyrus arbutifolia*)	N.S. & MI to FL & TX	5a
Arundo donax (FACU-, FACW)	VA, KY, & MO, s to FL & TX	7a
Asclepias incarnata (FACW+, OBL)	** Varieties exist ** N.S. to Man. & UT, s to FL, LA, & NM	3a
Aster novae-angliae (FACW-, FACW)	sw Que. to s Alta., s to centr. ME, DE, MD, NC, AL, MS, AR, OK, KS, & CO	4a
Atriplex patula (FAC, FACW) (Annual)	** Varieties exist ** Nfld. to B.C. s to N.S., SC, MO & CA	Varieties differ
Avicennia germinans (OBL)	FL - TX	8b

Table G-7: Species Range[1] (page 2 of 11)

Species Name (National Range of Indicator Status)	Range	Hardiness Zone [2]
Baccharis glutinosa (FACW-, FACW)	s CA (Deserts) to CO, TX, Mex. and South America	8a
Baccharis halimifolia (FAC, FACW)	Coastal MA, s to FL, TX, & Mex.	6b
Baccharis pilularis (not listed)	centr CA coast	9b
Bacopa caroliniana (OBL)	Coastal plain, se VA to s FL, w to e TX	7a
Batis maritima (OBL)	coastal plain NC - TX into Mex.; Los Angeles s to South America	7b
Betula nigra (FACW, OBL)	NH to MN, s to FL & TX	4a
Betula populifolia (FAC)	Que. w to sw Ont. s to N.S., N.E., DE, PA, upland VA, n OH, n IN	4a
Borrichia frutescens (FACW+, OBL)	e VA s to FL, TX, & e Mex.	7a
Calamagrostis canadensis (FAC, OBL)	Nfld. to Mackenz. & B.C., s to DE, PA, WV, n OH, n IN, IL, MO, NE, NM & CA	4b
Caltha palustris (OBL)	Lab - AK, s to Nfld., N.S., N.E., SC, TN, IA, and NE	3a
Carex aperta (FACW)	s B.C. to MT, s to UT, CA	5a
Carex aquatilis (OBL)	Nfld. & Que. to B.C. s to N.S., n & w N.E., n NJ, NY, s Ont., OH, MI, IN, WI, MO, NE, CO, OR	4a
Carex comosa (OBL)	w N.S., centr ME, sw Que., s Ont., MI, WI, MN, & NE, s to FL & LA; ID & WA, s to CA	4a
Carex hystricina (OBL)	Que. to Alta. & WA, s to P.E.I., N.B., N.E., NJ, D.C., upland to TN, MO, OK, TX, NM, AZ, CA	3a
Carex lacustris (OBL)	Que. to s Man., s to N.S., N.E., VA, OH, IN, IL, IA, SD	3a
Carex lanuginosa (OBL)	Que. to B.C. s to N.B., N.E., VA, TN, AR, OK, TX, NM, AZ, s CA	3a
Carex lenticularis (FACW+, OBL)	Lab. to Mackenz., s to Nfld., N.S., ME, NH, w MA, s Ont., MI, MN, Man., Sask., ID, s B.C.	3a
Carex lyngbyei (OBL)	Que., AK - CA	3b
Carex obnupta (OBL)	centr. CA n to s AK	4b
Carex retrorsa (FAC, OBL)	Que. to B.C., s to N.S., N.E., n NJ, PA, n OH, n IN, n IL, n IA, SD, CO, UT, WA	3a

Table G-7: Species Range[1] (page 3 of 11)

Species Name (National Range of Indicator Status)	Range	Hardiness Zone [2]
Carex rostrata (OBL)	** Varieties exist ** s Greenl. & Lab. to AK, s to Nfld., ne N.S., n N.B, n VT, n MI, Sask. mts. to CO, s CA	3a
Carex stipata (not listed)	s Lab., to s AK, s to Nfld, N.S., N.E., NC, TN, MO, KS, NM, CA	4a
Carex stricta (OBL)	N.B. to Ont., s to N.S., N.E., NC, OH, IN, IL, MN	3a
Carex trichocarpa (OBL)	sw Que. & VT to Ont. & MN, s to CT, DE, PA, OH, IN, IL, & n IA	3a
Carex vulpinoidea (OBL)	Nfld. to s B.C., WA, OR, s to FL w to Rocky Mts.	3a
Carya aquatica (OBL)	VA, w to IL & se MO, s to FL & TX	6b
Celtis occidentalis (FACU, FAC)	** Varieties exist ** Que. to Man., s to n FL, TN, AR, & OK	3b
Cephalanthus occidentalis (OBL)	N.B. & Que. to MN, s to FL, Mex., & CA	3b
Ceratophyllum demersum (OBL)	Que. to n B.C., s to FL, TX, & CA	3a
Chamaecyparis thyoides (OBL)	centr. ME, s to n FL & MS	5a
Cladium jamaicense (OBL)	se VA, s to FL, TX, & Mex.	7b
Clethra alnifolia (FAC+, FACW)	s ME, s to FL & e TX	4a
Cornus amomum (FACW, FACW+)	Que. to Ont. & s IL, s to SC & AL	5b
Cornus foemina racemosa (FAC, FACW) (Syn: *C. racemosa*)	centr. ME to s Ont. & MN, s to N.E., DE, MD, WV, KY, MO, & OK	4b
Cornus sericea (FAC, FACW+) (Syn: *C. stolonifera*)	Nfld. & s Lab. to Yuk,, s to N.S., N.E., WV, OH, IN, IL, IA, NE, NM, AZ, & CA	3a
Cymodocea filiformis (OBL) (Syn: *Syringodium filiformis*)	coastal FL - TX	8b
Cyperus esculentus (FAC, FACW)	N.S. & Que., w to WA, s throughout U.S.	3a
Deschampsia cespitosa (FAC, FACW+)	Nfld., MT to s B.C., s to CO & CA	4b
Distichlis spicata (FAC+, FACW+)	N.B. & P.E.I., s to FL & TX, locally inland to MO & along Pacific Coast	4a
Dulichium arundinaceum (OBL)	Nfld. to B.C., s to FL, TX and CA	4a
Eleocharis equisetoides (OBL)	MA & NY to MI & MO, s to centr FL & TX	5a

Table G-7: Species Range[1] (page 4 of 11)

Species Name (National Range of Indicator Status)	Range	Hardiness Zone [2]
Eleocharis obtusa (OBL) (Annual; Syn: *E. ovata*)	N.S. & N.B. to MN, s to nw FL, AL, MS, LA & e TX, also B.C. to n CA, CO, & NM	3a
Eleocharis palustris (OBL)	** Varieties exist ** s Lab. - B.C. s to N.S., s N.E., N.J., PA, s MI, IL, IA, SD, WY & n CA	4a
Eleocharis quadrangulata (OBL)	MA to Ont., MI, IL, WI, & MO, s to FL, TX, & OK	4a
Elodea canadensis (OBL) (Syn: *Anacharis canadensis*)	Gaspe Pen., Que., to Ung., w to WA, s to N.E., NC, AL, IL, IA, OK, CO, UT and CA	4a
Forestiera acuminata (OBL)	SC to n FL & TX, n to se KS, MO, s IN, IL, KY, & TN	6a
Frankenia grandifolia (FACW+)	Coastal CA	9b
Fraxinus caroliniana (OBL)	Coastal Plain, VA, s to FL, AR, & TX	7a
Fraxinus latifolia (FACW)	w base of Sierra Nevada, from n Kern (CA) to B.C.	4a Caution[3]
Fraxinus nigra (FACW, FACW+)	s Que. & s Ont., s to DE, VA, WV, OH, IN, IL, IA, w to MN & SD	3a
Fraxinus pennsylvanica (FAC, FACW)	ME, Ont. & Sask., s to FL & TX	3b
Gleditsia aquatica (OBL)	NC, s to centr FL, w to TX, n in interior to se MO, s IL, & s IN	6b
Glyceria grandis (OBL)	Nfld. to AK, s to VA, TN, IA, NM, & OR	4a
Glyceria septentrionalis (OBL)	e MA to s Ont., s to GA, KY, MO, & TX	4a
Gordonia lasianthus (FACW)	Coastal Plain from NC to centr FL, w to LA	8a
Grindelia humilis (FACW)	in CA: San Francisco, San Pablo, and Suisun Bays	9b
Halodule wrightii (OBL)	NC - FL to TX	8a
Hibiscus moscheutos (OBL)	MA to FL & AL, inland from w NY & s Ont. to n IL & IN	6a
Hydrocotyle umbellata (OBL)	N.S. to MN, s to FL, OK, & TX; OR & CA	5b
Ilex cassine (FACW)	VA to s FL, w to se TX	6b
Ilex decidua (FACW-, FACW)	Coastal Plain, MD to FL & TX, e OK, n to s IN, s IL, s MO, & KS	6a
Ilex glabra (FACW-, FACW)	N.S. to FL & LA (along Coastal Plain)	4a

Table G-7: Species Range[1] (page 5 of 11)

Species Name (National Range of Indicator Status)	Range	Hardiness Zone [2]
Ilex verticillata (FACW, OBL)	Nfld. to MN, s to GA & MS	3a
Iris pseudacorus (OBL)	Nfld. to MN, southward	3a
Iris versicolor (OBL)	Nfld. to Man., s to VA & MN	3a
Itea virginica (FACW+, OBL)	s NJ. s to FL & LA (along Coastal Plain), MS Valley n to IL	5a
Iva frutescens (FACW, FACW+)	N.S. & s NH, s to FL & TX	5b
Jaumea carnosa (OBL)	northern lower CA n to Puget Sound Region & Vancouver Island	8a
Juncus balticus (FACW, OBL)	** Varieties exist ** Lab. & Nfld. to B.C., s to PA & MO; s CA	3a
Juncus effusus (FACW+, OBL)	** Varieties exist ** Entire U.S.	3b
Juncus ensifolius (FACW, FACW+)	AK to the Sierra Nevadas & n coast ranges, CA e to Alta., UT & AZ	3a
Juncus roemerianus (OBL)	se DE & MD to FL & TX	7a
Juncus tenuis (FAC-, FACW)	** Varieties exist ** Throughout U.S.	3a
Juncus torreyi (FACW, FACW+)	MA to Sask., s to AL & TX, w to CA & n Mex.	3a
Laguncularia racemosa (FACW+)	FL	8b
Leersia oryzoides (OBL)	Que. - e WA, s to FL, AL, LA, TX, NM, AR, CA	3b
Lemna minor (OBL)	Nearly worldwide	3b
Leucothoe racemosa (FACW)	MA & se NY to e PA, s to FL & LA	5a
Limnobium spongia (OBL)	NY, s to n FL & e TX, interior to MO & s IL	7b
Lindera benzoin (FACW-, FACW) (Syn: *Benzoin aestivale*)	sw ME - s Ont., s MI and IL, s to FL & TX	3b
Liquidambar styraciflua (FAC, FACW)	s CT to s IL & OK, s to FL & Mex.	5b
Lobelia cardinalis (FACW+, OBL)	N.B. to MI & MN, s to FL & TX	3b
Lysichiton americanum (OBL)	Santa Cruz mts., n to AK, MT	4a
Lythrum salicaria (FACW+, OBL)	Que. & N.E. to MI, s to VA	3a
Magnolia virginiana (FACW+, OBL)	s NY, s to FL & TX (along Coastal Plain)	5b
Monanthochloe littoralis (OBL)	Santa Barbara, CA s; w to TX, FL and Mex.	9a
Myrica cerifera (FAC, FAC+)	s NJ, s to FL & TX	7a

Table G-7: Species Range[1] (page 6 of 11)

Species Name (National Range of Indicator Status)	Range	Hardiness Zone [2]
Myrica pensylvanica (FAC)	Nfld., s to NC (mainly Coastal Plain)	5b
Nasturtium officinale (OBL)	** Varieties exist ** throughout U.S.	3a
Nelumbo lutea (OBL)	NY & s Ont. to MN & IA, s to FL, e OK, & e TX	3b
Nuphar luteum (OBL)	** Varieties exist ** s ME to WI & NE, s to FL & TX	4a
Nymphaea odorata (OBL)	** Varieties exist ** Throughout U.S.	3a
Nyssa aquatica (OBL)	Coastal Plain, VA to n FL, w to e TX, n to interior to MO, s IL, s IN	6a
Nyssa sylvatica (FACW+, OBL)	ME to s Ont., s to FL & TX	3b
Onoclea sensibilis (FACW)	Nfld. & s Lab. to Man., s to FL, LA, & TX	3a
Osmunda cinnamomea (FACW, FACW+)	Nfld. - MN, s to FL, TX, & NM	3a
Osmunda regalis (OBL)	Nfld. - Sask., s to FL, TX, & Mex.	3a
Panicum hemitomon (FACW+, OBL)	Coastal Plain, NJ to FL, w to e & se TX, also TN	7a
Panicum virgatum (FAC, FACW)	Que. - Sask. s to FL, TX, & AZ	3a
Peltandra virginica (OBL)	s ME & sw Que. to MI, s Ont., & MO	4a
Persea barbonia (FACW) (Syn: *P. palustris*)	DE, s to FL & TX	7a
Phalaris arundinacea (FACW, OBL)	Nfld. - s AK s to NC, KS, & s CA	4b
Phragmites australis (FACW, FACW+)	N.S. & Que. to B.C., s to FL, TX, & CA	3a
Picea sitchensis (FACU, FAC)	Pacific coastal region from s AK to Mendocino (CA)	6a
Pinus elliotti (FACW)	SC, s to FL, w to LA	8a
Pinus rigida (FACU-, FACU)	se ME to e Ont., w NY, nw PA & e OH, s to VA, mts of GA, e TN & KY	4a
Pinus serotina (FACW+, OBL)	s NJ, s to FL & AL (Coastal Plain)	6a
Pinus taeda (UPL, FAC)	s NJ to FL & TX, w to TN & OK	7a
Platanus occidentalis (FAC, FACW)	s ME to MN, s to FL & TX	5a
Platanus racemosa (FACW)	centr & s CA	8a
Polygonum amphibium (OBL)	Lab. & N.S. to AK, s to VA, TX, & CA	4b

Table G-7: Species Range[1] (page 7 of 11)

Species Name (National Range of Indicator Status)	Range	Hardiness Zone [2]
Polygonum hydropiperoides (OBL)	** Varieties exist ** N.S. to B.C., s throughout U.S.	3a
Polygonum pensylvanicum (FACW-, OBL) (Annual)	** Varieties exist ** N.S. & Que. to MN & SD, s to FL & TX	4a
Polygonum persicaria (FAC, OBL) (Annual)	** Varieties exist ** Throughout U.S.	3a
Polygonum punctatum (FACW, OBL)	** Varieties exist ** Que. to B.C., s to FL & CA	3a
Pontederia cordata (OBL)	N.S. to Ont. & MN, s to n FL & TX	4a
Populus balsimifera (FACU, FACW) (Syn: *P. trichocarpa*)	AK to s CA w to ID & NV	5b
Populus deltoides (FAC, FACW)	sw Que. - Man., s to n FL & TX	3b
Populus fremontii (FACW-, FACW)	** Varieties exist ** w mountains of CA e to UT & NM	6a
Potamogeton diversifolius (OBL)	ME to WI, MT, & OR, s to Gulf States	4a
Potamogeton nodosus (OBL) (Syn: *P. americanus*)	Throughout U.S.	3b
Potamogeton pectinatus (OBL)	Que. & Nfld. to AK & B.C., s to FL, TX, & s CA	3a
Potamogeton perfoliatus (OBL)	** Varieties exist ** Nfld. & Que. to OH, s to FL & LA	3a
Quercus bicolor (FACW+, OBL)	ME & Que. to MN, s to VA & MO, upland GA, KY, AR, OK	4a
Quercus lyrata (OBL)	s NJ to FL & TX, n to IL & IN	5b
Quercus nigra (FAC, FACW)	DE to se MO & OH, s to FL & TX (chiefly along Coastal Plain)	6a
Quercus nuttallii (FACW, OBL)	AL - TX, n to se MO & AR	6b
Quercus palustris (FAC, FACW)	VT & s Ont., s to NC & OK	4a
Quercus phellos (FAC+, FACW)	s NY to s IL, s to FL & TX	5b
Rhizophora mangle (OBL)	FL	8b
Rosa californica (FAC+)	** Varieties exist ** Lower CA, n to s OR	6a
Rosa palustris (OBL)	N.S. & N.B. to MN, s to FL & AR	4a
Rubus spectabilis (FACU, FAC+)	** Varieties exist ** n CA n to AK, e to ID	4a
Rubus ursinus (FACW) (Syn: *R. vitifolius*)	through most of B.C. and ID s along coast to Lower CA	6a
Rumex verticillatus (FACW, OBL)	Que. & Ont. to WI & KS, s to FL & TX	3a

Table G-7: Species Range[1] (page 8 of 11)

Species Name (National Range of Indicator Status)	Range	Hardiness Zone [2]
Ruppia maritima (OBL)	** Varieties exist ** Entire U.S.	Varieties differ
Sagittaria graminae (OBL)	** Varieties exist ** Nfld. & Lab to Ont. s to FL & TX, w to OH, IN, MO, IL	2b
Sagittaria latifolia (OBL)	** Varieties exist ** N.B. - s B.C. s to FL, CA, & Mex.	3b
Sagittaria platyphylla (OBL) (Syn: *S. graminae var. platyphylla*)	s MO & KS to AL, LA, & TX	6a
Sagittaria rigida (OBL)	sw Que., s ME to MN, s to VA, KY, TN, MO, NE	3b
Salicornia virginica (OBL)	s NH - FL & TX; also AK to CA	Varieties differ
Salix boothii (OBL) (Syn: *S. pseudocordata*)	s B.C. through WA & OR e of Cascade Mts. & high Sierras of CA, e to Sask. & s in Rockies to NM	5a
Salix drummondiana (FACW, OBL)	centr CA to B.C., Rocky Mts.	4a Caution [3]
Salix exigua (FACW, OBL)	s CA (Deserts) to B.C., TX	4a Caution [3]
Salix gooddingii (FACW, OBL)	UT - TX & Mex.	6a
Salix hindsiana (FACW) (Syn: *S. sessifolia*)	central valley of CA, s OR to n Baja	6a
Salix hookeriana (FACW-, FACW)	Mendocino (CA), n to B.C.	4a Caution [3]
Salix laevigata (not listed) (Syn: *S. bonplandiana*)	UT - Baja CA	6a
Salix lasiandra (FACW, OBL) (Syn: *S. caudata*)	s CA - AK w to Sask., MT, WY, CO & NM	3a
Salix lasiolepis/Salix alba (FACW)	WA - n Mex.	5b
Salix lutea (FACW+, OBL)	n Ont. to Alta., s to nw IA, NE, CO, UT, CA, AR	2b
Salix nigra (UPL, OBL)	s Canada to centr MN, s to FL & TX	4a
Salix purpurea (FACW)	** Varieties exist ** Nfld. - Ont. & WI, s to N.S., N.E., VA, WV, OH, IL, IA	3a
Sambucus canadensis (UPL, FACW)	N.S. to Man. & SD, s to FL & TX	3a
Saururus cernuus (OBL)	s N.E., s Que. & MN, s to FL & TX	3a
Scirpus acutus (OBL)	Nfld. to B.C., s to N.S., New Eng., n NJ, PA, OH, IN, IL, MO, OK, TX, NM, AZ, & CA	3a

Table G-7: Species Range[1] (page 9 of 11)

Species Name (National Range of Indicator Status)	Range	Hardiness Zone [2]
Scirpus americanus (OBL) (Syn: *S. olneyi*)	NH & w N.S. to FL & Mex., inland NY, MI, & western states	5b
Scirpus californicus (OBL)	Gulf States to s CA	8a
Scirpus cyperinus (FACW+, OBL)	Nfld. to MN, s to FL & LA	4a
Scirpus fluviatilis (OBL)	w N.B. to Sask. & WA s to ne VA, OH, IN, IL, MO, KS, NM, CA	3b
Scirpus maritimus (OBL)	ne N.B. to VA, w NY	4b
Scirpus microcarpus (OBL)	Throughout cismontane CA, CA to AK, e to NM, NV, CO, MN, CT, & Nfld.	4a
Scirpus pungens (FACW+, OBL) (Syn: *S. americanus*)	Nfld., Que., MN, & NE, s to FL & TX	3b
Scirpus robustus (OBL)	N.S. to FL & TX; CA	5b
Scirpus validus (OBL)	Nfld. to s AK, s to FL, OK, TX, NM, n Mex., CA	4a
Sesuvium portulacastrum (FACW)	NC - s FL, w to TX	7a
Sium suave (OBL)	Nfld. to B.C., s to FL, LA, & CA	4a
Sparganium americanum (OBL)	Nfld. & Que. to MN, s to FL & LA	3a
Sparganium emersum (OBL) (Syn: *S. angustifolium*)	Lab. to AK, s to Nfld., N.S., N.E., mts. of NJ & PA, MI, n IL, MN, CO and CA	3a
Sparganium eurycarpum (OBL)	Que. & N.S. to s B.C., s to FL, OH, IN, IL, MO, KS, CO, UT, CA	5b
Spartina alterniflora (OBL)	** Varieties exist ** Que. & Nfld. to FL & TX	4b
Spartina cynosuroides (OBL)	MA to FL & TX	5b
Spartina foliosa (OBL)	Pacific coast	8a
Spartina patens (FACW, OBL)	sw Nfld. - s St. Lawrence, Que. s to FL & TX, inland to w NY & se MI	4a
Spartina pectinata (FACW, OBL)	Nfld. - Alta. & WA s to N.S., N.E., w NC, WV, IN, IL, MO, TX, NM, OR	4b
Spiraea douglasii (UPL, OBL)	n CA, n to B.C.	4a Caution [3]
Spirodela polyrhiza (OBL)	se Que. & s Ont. to s B.C., s to FL, TX, & Mex.	3b
Suaeda californica (FACW+)	coastal CA	9b
Symplocarpus foetidus (OBL)	Que. to se Man., s to NC & IA, upland to GA & TN	3a

Table G-7: Species Range[1] (page 10 of 11)

Species Name (National Range of Indicator Status)	Range	Hardiness Zone [2]
Taxodium ascendens (not listed) (Syn: *T. distichum var. nutans*)	VA to FL & AL	7a
Taxodium distichum (OBL)	s NJ, s to FL & TX, MS Valley, n to s IL & IN	6a
Thalassia testudinum (OBL)	FL - TX	8b
Thelypteris noveboracensis (FAC, FAC+)	Nfld. - s Ont., MI & n IL, s to N.S., N.E., GA, AL, MI & AR	4a
Thelypteris palustris (FACW+, OBL)	s Nfld. - se Man., s to FL & TX	4a
Thuja occidentalis (FACW)	e Que. to Sask., s to N.S., n & w N.E., NY s along mts to NC & TN, OH, n IN, ne IL, WI, MN	3a
Thuja plicata (FAC, FAC+)	Medocino (CA) n to AK, w MT	4a
Triglochin concinnum (OBL)	ND w to OR s to CA, NM, & AZ	3b
Triglochin maritimum (OBL)	Lab. to AK, s to NJ & DE, inland to Nfld. & ND, s to AZ & NM	3a
Typha angustifolia (OBL)	N.S. & s ME to s Que. & Ont. s to FL & TX, KY, MO, NB, & CA *Aggressive* In some areas considered undesirable	4b
Typha latifolia (OBL)	Nfld. - AK, s to FL & Mex. *Aggressive* In some areas considered undesirable	3a
Ulmus americana (FAC, FACW)	Nfld. - Sask., s to n FL, LA & TX	3a
Vaccinium corymbosom (FACW-, FACW)	N.S. to s Que., w to WI, s to FL & TX	4a
Vallisneria americana (OBL)	s N.B. to ND, s to FL & TX	4a
Vallisneria spiralis (not listed)	s N.B. to ND, s to FL & Gulf States	3b
Viburnum dentatum (FAC)	se MA, s to FL & TX, w to PA, WV, & TN	7a
Viburnum lentago (FACU, FAC+)	w Que. to Man., s to GA & MS	2b
Viburnum trilobum (FAC, FACW)	Nfld. - B.C. s to NY, MI, SD, & OR	3a
Woodwardia areolata (FACW+, OBL)	N.S., s to FL & TX (mainly along coast), w to MI & MO)	5b
Zizania aquatica (OBL) (Annual)	** Varieties exist ** e Que. & N.S. to Man., s to FL & LA	4a
Zizaniopsis miliacea (OBL)	MD to s FL, w to TX, n to KY, AR, OK, & se MO	7a
Zostera marina (OBL)	** Varieties exist ** East coast: Canada - NC West coast: Canada - Gulf of CA	5a

Table G-7: Species Range[1] (page 11 of 11)

1. Abbreviations:

   n - north, northern
   s - south, southern
   e - east, eastern
   w - west, western
   centr - central

   Alta. - Alberta
   Greenl. - Greenland
   Lab. - Labrador
   Mackenz. - Mackenzie
   Man. - Manitoba
   Mex. - Mexico
   N.B. - New Brunswick
   N.E. - New England
   N.S. - Nova Scotia
   Nfld. - Newfoundland
   Ont. - Ontario
   P.E.I. - Prince Edward Island
   Que. - Quebec
   Sask.- Saskatchewan
   Ung. - Ungava District, Canada
   Yuk. - Yukon Territory

2. Hardiness zones are taken from the *New USDA Plant Hardiness Zone Map*, published in January 1990. Without a and b designations the hardiness zones given here are roughly equivalent to the previous 1965 map; however, the new map is considered more accurate.

3. British Columbia, which in the literature is reported to be the northernmost limit of this species, contains Hardiness Zones 1 through 9a. It is not clear which part of B.C. this species extends to, however; therefore, the northernmost Hardiness Zone in the United States into which this species falls has been indicated. The species may, however, tolerate a more extreme Hardiness Zone.

Table G-8: Special Characteristics (page 1 of 8)

Species Name	Shade Tolerance [1]	Rate of Spreading [2]	Salinity [3]	Other
Acer macrophyllum		NA		Elevation: Northern part of range: 0 - 3,300 ft. Southern part of range: 0 - 6,600 ft.
Acer negundo	None	NA	Resistant	
Acer rubrum	Partial	NA		Rapid grower
Acer saccharinum	Partial	NA	Resistant	
Acorus calamus	Partial	Moderate	Low	Tolerates acidic conditions Soil stabilizer
Alisma plantago-aquatica				Grows well from seed (in shallow, quiet waters)
Alnus rhombifolia		NA		Nitrogen fixing Rapid grower
Alnus rubra (Syn: *A. oregona*)		NA		Nitrogen fixing Elevation: Below 500 ft.
Alnus serrulata	None	NA		Nitrogen fixing
Amelanchier canadensis	Full	NA	Resistant	
Amorpha fruticosa	None	NA	Resistant	
Andropogon virginicus		Slow		Transitional (Buffer) plant
Arisaema triphyllum	Full			
Aronia arbutifolia (Syn: *Pyrus arbutifolia*)	Partial	Slow	Resistant	Spreads by suckers
Arundo donax		Rapid	Low	Invasive (Considered pest species in some states)
Aster novae-angliae	Partial	Slow		
Avicennia germinans			High	Tolerates colder temps Soil stabilizer
Baccharis glutinosa	Full	NA		Elevation: Up to 2500 ft.
Baccharis halimifolia	None	NA	High	pH Tolerance: 4.0 - 7.5
Baccharic pilularis	None	Slow	High	
Bacopa caroliniana			High	
Batis maritima		Rapid		
Betula nigra	None	NA		Sprouts readily from cutting
Betula populifolia	None	NA	Resistant	
Borrichia frutescens			High	Soil stabilizer
Calamagrostis canadensis				Soil stabilizer

Table G-8: Special Characteristics (page 2 of 8)

Species Name	Shade Tolerance [1]	Rate of Spreading [2]	Salinity [3]	Other
Caltha palustris	Partial	Slow		
Carex aquatilis	Partial	Moderate		Streambank stabilizer
Carex comosa	Partial	Slow		
Carex hystricina	None	Moderate		
Carex lacustris	None	Rapid		
Carex lanuginosa				Robust Streambank stabilizer
Carex lenticularis				Pioneer species Streambank stabilizer
Carex lyngbyei			High (up to 20 ppt)	
Carex obnupta	None	Moderate	Low	
Carex retrorsa	Full	Slow		
Carex rostrata	Partial			Streambank stabilizer
Carex stipata	Partial	Slow		
Carex stricta	None	Moderate		Acid tolerant
Carex vulpinoidea	Partial	Slow		
Carya aquatica	Partial	NA		
Celtis occidentalis	Full		Resistant	Can be used in buffer; Seedlings cannot tolerate submergence
Cephalanthus occidentalis	Full	NA	Resistant	Sprouts readily from cutting
Ceratophyllum demersum	Full	NA		Turbidity not as limiting Absorbs nutrients in water column
Cladium jamaicense		Rapid	Resistant	Forms dense tussocks
Clethra alnifolia	Full	Slow	Resistant	Spreads by suckers Tolerates acidic soil
Cornus amomum	None	NA		
Cornus foemina racemosa (Syn: *C. racemosa*)	Full	NA		
Cornus sericea (Syn: *C. stolonifera*)	Partial	Slow		Spreads by stolons
Cymodocea filiformis (Syn: *Syringodium filiformis*)		Rapid	High	Temp. range: 23 - 29° C
Deschampsia cespitosa		Slow	High (up to 20 ppt)	Soil stabilizer

Table G-8: Special Characteristics (page 3 of 8)

Species Name	Shade Tolerance [1]	Rate of Spreading [2]	Salinity [3]	Other
Distichlis spicata	None	Moderate	High (up to 50 ppt)	
Dulichium arundinaceum				
Eleocharis palustris	Partial	Moderate		Alkali tolerant
Eleocharis quadrangulata		Slow		
Elodea canadensis (Syn: *Anacharis canadensis*)		Rapid	Low	Absorbs excess nutrients; Considered undesirable in some areas (clogs waterways)
Forestiera acuminata	Full			Sprouts readily from cutting
Frankenia grandifolia	None	Slow	High	
Fraxinus latifolia		NA		Elevation: Below 5500 ft.
Fraxinus nigra	None	NA	Resistant	pH tolerance: 4.6 - 6.5
Fraxinus pennsylvanica	Partial	NA	Resistant	
Gleditsia aquatica	None	NA		
Gordonia lasianthus	None	NA		
Grindelia humilis	None	Slow	Low	
Halodule wrightii		Moderate	3.5 - 44 ppt	
Hibiscus moscheutos	None	Slow	Low	
Ilex cassine		NA	Low	
Ilex decidua	Full	NA	Resistant	
Ilex glabra	Partial	NA	Resistant	
Ilex verticillata	Partial	NA		Male + Female needed for berries (other Ilex species will pollinate)
Iris pseudocorus	No flowers: Partial For flowers: None	Slow		Stay clumped
Iris versicolor	No flowers: Partial For flowers: None	Slow		Stay clumped
Itea virginica	Full	NA	Resistant	pH tolerance = 5.0 - 7.0
Iva frutescens	None	NA	Low	pH tolerance = 6.0 - 7.5
Jaumea carnosa				Spreads well
Juncus balticus	Partial	Slow		Elevation: Below 5000 ft. Limits invasive establishment
Juncus effusus		Slow	Low	Propagates naturally from seed once transplanted
Juncus ensifolius	Partial			Elevation: to 9000 ft.

Table G-8: Special Characteristics (page 4 of 8)

Species Name	Shade Tolerance [1]	Rate of Spreading [2]	Salinity [3]	Other
Juncus roemerianus		Moderate	High	Nitrogen fixing pH tolerance = 3.5 - 7.2
Juncus tenuis	Partial	Slow		
Juncus torreyi	Partial	Slow		Alkali tolerant
Laguncularia racemosa			High	
Leersia oryzoides	Full	Moderate		Soil stabilizer
Limnobium spongia				pH tolerance = 6.0 - 7.0
Lindera benzoin (Syn: *Benzoin aestivale*)	Full	NA	Resistant	
Liquidambar styraciflua	None	Slow	Resistant	Spreads by suckers
Lobelia cardinalis	Partial	Slow		High aesthetic value
Lythrum salicaria		Rapid		Highly invasive (Considered pest species in some states.)
Magnolia virginiana	Partial	NA	Resistant	
Monanthochloe littoralis		Rapid		
Myrica cerifera		Slow	Low	Evergreen Spreads by suckers Nitrogen fixing
Myrica pensylvanica	Partial	Slow	Low	Spreads by suckers Nitrogen fixing Male + Female needed for seed production
Nuphar luteum		Slow	Resistant	
Nyssa aquatica	None	NA		
Nyssa sylvatica	Partial	Slow	Resistant	Spreads by suckers Male / Female flowers on different trees
Onoclea sensibilis	Full	Moderate		
Osmunda cinnamomea	Full	Slow		
Osmunda regalis	Full	Slow		
Panicum virgatum		Slow	Low	Transitional: For buffer zone
Peltandra virginica	Partial	Slow		
Persea barboni (Syn: *P. palustris*)	Full	NA		
Phalaris arundinacea		Rapid		Soil stabilizer Invasive (Considered pest species in some states.)

Table G-8: Special Characteristics (page 5 of 8)

Species Name	Shade Tolerance [1]	Rate of Spreading [2]	Salinity [3]	Other
Phragmites australis	None	Rapid	High (up to 20 ppt)	pH tolerance = 3.7 - 9.0 Soil stabilizer; Highly invasive (Considered pest species in some states.)
Picea sitchensis		NA		Elevation: Sea level to 3300 ft. Rapid grower
Pinus elliotti		NA		Seedlings survive long periods of flooding & submergence up to a month
Pinus rigida	None	NA	Resistant	Found mostly in sandy soil
Pinus taeda		NA		Rapid grower
Platanus occidentalis	Partial	NA		
Polygonum hydropiperoides	Partial			
Pontederia cordata	Partial	Moderate		
Populus deltoides	None	NA	Resistant	
Populus fremontii		NA		Elevation: 0 - 6,900 ft.
Potamogeton pectinatus		Rapid	Low	Tolerates alkali water Tolerates strong currents
Potamogeton perfoliatus		Rapid	Low	Tolerates quiet waters only
Quercus bicolor	Partial	NA	Resistant	
Quercus nigra		NA		Rapid grower
Quercus palustris	None	NA	Resistant	Seedlings intolerant to standing water
Quercus phellos	Partial	NA		Rapid grower
Rhizophora mangle		NA	High	
Rosa californica		NA		Elevation: below 6000 ft.
Rubus spectabilis		NA		Elevation: below 1000 ft.
Rumex verticillatus		Slow		Readily propagated from rhizomes
Ruppia maritima		Rapid	High	Temp. range: 7 - 35° C
Sagittaria latifolia	Partial	Rapid		
Sagittaria platyphylla (Syn: *S. graminae var. platyphylla*)		Rapid		
Sagittaria rigida			Resistant	
Salicornia virginica	None	Rapid	High (up to 60 ppt)	Establishes quickly

Table G-8: Special Characteristics (page 6 of 8)

Species Name	Shade Tolerance [1]	Rate of Spreading [2]	Salinity [3]	Other
Salix boothii (Syn: *S. pseudocordata*)		Slow		Spreads by suckers Roots freely Elevation: 10,000 - 12,000 ft. in the south
Salix drummondiana		Slow		Spreads by suckers Streambank stabilizer Elevation: 8400 - 9500 ft. Roots freely
Salix exigua		Slow		Spreads by suckers Streambank stabilizer Elevation: below 800 ft. Easily rooted
Salix gooddingii		Slow		Spreads by suckers Streambank stabilizer Requires long, hot growing season. Elevation: 200 - 4,000 ft.
Salix hindsiana (Syn: *S. sessifolia*)		Slow		Spreads by suckers Streambank stabilizer Elevation: 0 - 3,000 ft.
Salix hookeriana		Slow		Spreads by suckers Streambank stabilizer Elevation: Below 500 ft.
Salix laevigata (Syn: *S. bonplandiana*)		Slow		Spreads by suckers Streambank stabilizer Elevation: 0 - 4,400 ft.
Salix lasiandra (Syn: *S. caudata*)		Slow		Spreads by suckers Streambank stabilizer Elevation: 0 - 8,400 ft.
Salix lasiolepis/Salix alba		Slow		Spreads by suckers Streambank stabilizer Elevation: 0 - 7,400 ft.
Salix lutea		Slow		Spreads by suckers Streambank stabilizer Easily rooted
Salix nigra	None	Slow		Spreads by suckers Streambank stabilizer Rapid grower
Salix purpurea		Slow		Spreads by suckers Streambank stabilizer
Sambucus canadensis	Full	Slow		Spreads by suckers
Saururus cernuus	Partial	Rapid		
Scirpus acutus			Low	
Scirpus americanus (Syn: *S. olneyi*)		Rapid	Low	

Table G-8: Special Characteristics (page 7 of 8)

Species Name	Shade Tolerance [1]	Rate of Spreading [2]	Salinity [3]	Other
Scirpus californicus	None	Moderate	Low	Soil stabilizer
Scirpus cyperinus	None	Moderate		
Scirpus fluviatilis	Partial	Moderate		
Scirpus maritimus		Rapid	Low	
Scirpus microcarpus				Elevation: Up to 9000 ft.
Scirpus pungens (Syn: *S. americanus*)		Rapid	Low	Soil stabilizer
Scirpus robustus	None	Moderate	High (fluctuating, up to 25 ppt)	
Scirpus validus	None	Rapid	Low	
Sesuvium portulacastrum			Low	
Sium suave		Slow		
Sparganium americanum	Partial	Rapid		
Sparganium eurycarpum	Partial	Rapid		
Spartina alterniflora	None	Rapid	High	Soil stabilizer
Spartina cynosuroides	None	Moderate	Low	Soil stabilizer
Spartina foliosa	None	Moderate	High	
Spartina patens	None	Moderate	High	
Spartina pectinata	None	Moderate	Low	
Spiraea douglasii		NA		Elevation: below 6000 ft.
Suaeda californica			High	
Symplocarpus foetidus	Full	Slow		
Taxodium ascendens (Syn: *T. distichum var. nutans*)	Partial	NA		pH tolerance = 3.6 - 5.4
Taxodium distichum	Partial	NA		
Thalassia testudinum		Slow	High	Tolerant of strong currents; Temp. range: 20 - 36° C (Optimum: 28 - 30° C)
Thelypteris noveboracensis	Full			
Thelypteris palustris	Full	Moderate		
Thuja occidentalis	Partial	NA		Alkaline soils
Thuja plicata		NA		Elevation: Sea level - 5900 ft. Slow growing
Triglochin concinnum	None	Slow	High	

Table G-8: Special Characteristics (page 8 of 8)

Species Name	Shade Tolerance [1]	Rate of Spreading [2]	Salinity [3]	Other
Triglochin maritimum	None	Slow	High	
Typha angustifolia	None	Rapid	Low	Soil stabilizer Invasive (Considered pest species in some states.) pH range: 3.7 - 8.5
Typha latifolia	None	Rapid		Soil stabilizer Invasive (Considered pest species in some states.)
Ulmus americana	Full	NA		
Vaccinium corymbosom	Full	Slow	Resistant	Spreads by suckers pH tolerance = 4.0 - 5.0
Vallisneria americana	Tolerates turbidity	Rapid	Resistant	
Viburnum dentatum	Partial	Slow	Resistant	Spreads by suckers
Viburnum lentago	Full			
Viburnum trilobum	Full			
Woodwardia areolata	Full			
Zizania aquatica (Annual)	None	NA	Resistant	Annual
Zizaniopsis miliacea		Rapid		Invasive (possible nuisance species)
Zostera marina		Moderate	High	Holds nitrogen-fixing bacteria in root system Temp. range: 0 - 30° C

NOTE: The Research Team recommends that the use of invasive species usually should be avoided or minimized in wetland replacement. Some of the listed invasive species are on state noxious weed lists and therefore may be illegal to plant/propagate. They have been listed here to warn users of the manual that they are in fact considered invasive and can out-compete other wetland species rapidly to the point of dominating a wetland replacement project. Their use should be avoided.

1. All plants listed herein will tolerate full sunlight unless otherwise indicated.

2. **Rapid**: > 1 ft. per yr. in unconsolidated soils
   Moderate: 0.5± ft. per yr. in unconsolidated soils
   Slow: < 0.2 ft. per yr. in unconsolidated soils
   NA: Not Applicable

3. **Resistant**: Tolerates infrequent salt-water flooding and/or salt spray.
   Species identified as such here are not listed in the Tidal Saltwater Table.
   Low: Tolerates salinities of at least 2 ppt but probably not greater than 10 ppt.
   High: Tolerates salinities of at least 10 ppt but probably not greater than 33 ppt (unless otherwise noted).

Table G-9: Wildlife Value ** (page 1 of 13)

Species Name	Benefits Provided	Which Species
Acer macrophyllum	Seeds	Squirrel, Chipmunk, Mice, Evening grosbeak
	Saplings, Young twigs, Leaves	Mule deer, Elk
Acer negundo	Seeds	Squirrel, Mice, Upland gamebirds, Songbirds, Waterbirds, Grosbeak
	Young twigs, Leaves	White-tailed deer
Acer rubrum	Nesting, Cover	American robin, Prairie warbler, American goldfinch
	Seeds	Waterbirds, Bobwhite, Cardinal, Pine siskin, Evening grosbeak, American goldfinch, Yellowbellied sapsucker
	Food	Hoofed browsers
Acer saccharinum	Seeds	Waterbirds, Bobwhite, Cardinal, Evening grosbeak, Pine grosbeak
	Cover, Nesting	Northern oriole, American goldfinch
	Food	Hoofed browsers
Acorus calamus	Food, Cover	Many species of waterfowl, Muskrat
Agrostis alba	Food	Cottontails, Some birds
Alnus rhombifolia	Browsing	Deer, Moose
	Seeds	Small birds
Alnus serrulata	Cover, Nesting	American woodcock, Willow flycatcher, Fox sparrow, Alder flycatcher, Yellow warbler, Wilson's warbler, Red-winged blackbird, Rusty blackbird, Ruffed grouse, Beaver
	Seeds	Mallard, American wigeon, Green-winged teal, Bufflehead, Turkey, Common redpoll, Pine siskin, American goldfinch, Muskrat, Beaver, Cottontail rabbit, White-tailed deer, Woodcock, Ruffed grouse, Songbirds
Amelanchier canadensis	Food	Ruffed grouse, Hairy woodpecker, Tufted titmouse, Red-winged blackbird, Eastern bluebird, Cedar waxwing
	Cover, Nesting	Eastern kingbird, American robin, Woodthrush
Amorpha fruticosa	Food, Cover	Waterfowl, Marshbirds, Shorebirds, Small mammals
Andropogon sp.	Seeds	Finch, Junco, Field and Tree sparrow
	Plants	Antelope, Bison, White-tailed deer
Arisaema triphyllum	Fruit, leaves	Upland gamebirds (e.g., Ring-necked pheasant), Wood thrush

Table G-9: Wildlife Value ** (page 2 of 13)

Species Name	Benefits Provided	Which Species
Aronia arbutifolia (Syn: *Pyrus arbutifolia*)	Fruit	Bobwhite, Brown thrasher, Cedar waxwing, Eastern meadowlark, Fur & game mammals, Small & hoofed mammals; also serve as emergency food in winter for many species
Arundo donax	Seed source (Low value)	
Asclepias incarnata	Food	Pronghorn antelope
	Roots	Muskrat (sparingly)
Avicennia germinans	Detritus - food	Many fish species
	Surface	Attached invertebrates, oysters
	Nursery	Many fish species
	Harbors food	Wading birds
Baccharis halimifolia	Cover, Nesting, Breeding	Songbirds, Waterfowl, Shorebirds
Baccharis pilularis	Cover	Mule deer, Small mammals
	Nesting	Long-billed marsh wren
Bacopa caroliniana	Cover	
Betula nigra	Seeds	Sharp-tailed grouse, Ruffed grouse, Spruce grouse, Redpoll, Pine siskin
	Twigs and Foliage	Moose, White-tailed deer
	Various parts	Beaver, Hare, Porcupine
Betula populifolia	Seeds	Green-winged teal, Wood duck, Bufflehead, Great blue heron, Turkey, Ring-necked pheasant, Blue jay, Black-capped chickadee, Northern junco, Others
	Cover, Nesting	Black-capped chickadee
	Grazing	Hoofed browsers
Borrichia frutescens	Cover, Nesting (Low food value)	
Calamagrostis canadensis	Food, Cover, Nesting	
	Seeds	Variety of birds
	Grazing	Mammals, especially rodents (muskrat)
	Sprouts	Moose, Deer
Caltha palustris	Seeds	Upland game birds
	Food	Moose
Carex sp. (cont'd)	Food	Rails (Sora, Yellow), Grouse, Snipe, Seed-eating songbirds, Swamp sparrow, Tree sparrow, Lincoln sparrow, Snow bunting, Larkspurs, Redpoll, Ruffed grouse chicks, Black duck, Moose, Elk

Table G-9: Wildlife Value ** (page 3 of 13)

Species Name	Benefits Provided	Which Species
Carex sp. (cont'd)	Cover	Many species
Carya aquatica	Nuts, bark, leaves	Wood duck, Wild turkey, Fox squirrel, Gray squirrel, Red squirrel, Chipmunk, White-tailed deer, White-footed mouse
Celtis occidentalis	Food (Fruit)	Upland gamebirds, Songbirds (e.g., Mockingbird, Robin), Terrestrial furbearers, Small mammals, Deer
Cephalanthus occidentalis	Seed	Mallard, Wigeon, Shoveller, Wood duck, Teals
	Nesting	Virginia rail, Red-winged blackbird
	Nectar	Ruby-throated hummingbird
	Attracts	Muskrat, Beaver
Ceratophyllum demersum	Food (Plants, Seed)	Mallard, Black duck, Coot, Blue & Green winged teal, Marshbirds, Shorebirds; CARP RESISTANT
	Cover	Fish, Shrimp
	Supports insects	Fish
Chamaecyparis thyoides	Winter browse and food	White-tailed deer, Pine siskin
	Seedlings	Cottontail rabbit, Meadow mouse
	Food	Hessel's hairstreak butterfly
	Community	Bear, Beaver, Otter, Deer; Parula, Prairie, Prothonotory, Hooded & Worm-eating warblers; Cooper's hawk, Red-shouldered hawk, Barred owl, Ovenbird, Yellow throat, Others
Cladium jamaicense	Food	Not a choice duck food but seeds are eaten in small quantities by waterfowl, marshbirds, & shorebirds
	Cover	Waterfowl, Mink
Clethra alnifolia	Food, Cover	Songbirds, Shorebirds, Waterfowl, Upland gamebirds, Small mammals
Cornus amomum	Fruit	Waterfowl, Downy woodpecker, Cedar waxwing, Common flicker, Eastern bluebird
	Cover & Preferred nesting	Gray catbird
	Food	White-tailed deer, Wild turkey, Beaver, Pileated woodpecker, Ruffed grouse, Bobwhite quail, Ring-necked pheasant, Cottontail rabbit, Woodchuck, Raccoon, Squirrel
Cornus foemina racemosa (Syn: *C. racemosa*)	Fruit	Ruffed grouse, Bobwhite, Turkey, Common flicker, Swainson's thrush, Eastern bluebird, Cedar waxwing, Waterfowl
(cont'd)	Cover	American woodcock

Table G-9: Wildlife Value ** (page 4 of 13)

Species Name	Benefits Provided	Which Species
C. foemina racemosa (cont'd)	Food	White-tailed deer, Beaver, Ring-necked pheasant, Cottontail rabbit, Woodchuck, Raccoon, Squirrel
Cornus sericea (Syn: *C. stolonifera*)	Food	Eastern kingbird, Brown thrasher, Purple thrush, Ring-necked pheasant, White-tailed deer, Wild turkey, Beaver, Ruffed grouse, Bobwhite quail, Cottontail rabbit, Woodchuck, Raccoon
	Cover, Nesting	American goldfinch
Cymodocea filiformis (Syn: *Syringodium filiformis*)	Food	Sea turtles, Many species of waterfowl
	Shelter, Food, Nursery	Scallop, Shrimp, Lobster, Grouper
	Concentrate food sources	Heron, Egret, Spoonbill, Cormorant, Pelican
Cyperus esculentus	Seeds, Rhizomes	Waterfowl, Upland gamebirds, Songbirds, Terrestrial furbearers, Small mammals
Distichlis spicata	Seed heads, young plants, rootstocks	Shoveller, Teals, Canada goose
	Seeds	Ground squirrel (CA)
Dulichium arundinaceum	Food	Muskrat, Wildfowl (slight importance)
Eleocharis equisetoides	Seeds, Rhizomes	Baldpate, Black, and Mottled duck, Teals, Canada goose, Rails, Muskrat, Prairie vole
Eleocharis obtusa (Syn: *E. ovata*)	Food	Waterfowl, Prairie vole
Eleocharis palustris	Food	Waterfowl, Prairie vole
Eleocharis quadrangulata	Seeds, Rhizomes	Baldpate, Black, and Mottled duck, Teals, Canada goose, Rails, Muskrat
Elodea canadensis (Syn: *Anacharis canadensis*)	Low waterfowl value (rarely produces seed)	
	Habitat	Small aquatic life
	Food	Beaver
Forestiera acuminata	Seeds	Waterfowl
Fraxinus sp.	Seeds	Wood duck, Bobwhite, Red-winged blackbird, Cardinal, Purple finch, Pine grosbeak
	Sap	Yellow-bellied sapsucker
	Cover, Nesting	Mourning dove, Evening grosbeak
	Browsing	White-tailed deer
Glyceria sp.	Food	Waterfowl, Muskrat
	Grazing	Deer (heavily)
Grindelia humilis	Cover	Salt marsh harvest mice

Table G-9: Wildlife Value ** (page 5 of 13)

Species Name	Benefits Provided	Which Species
Halodule wrightii	Food	Sea turtles, Many species of waterfowl
	Shelter, Food, Nursery	Scallop, Shrimp, Lobster, Grouper
	Concentrate food sources	Heron, Egret, Spoonbill, Cormorant, Pelican
Hibiscus moscheutos	Limited	
	Nectar	Ruby-throated hummingbird
Hydrocotyle umbellata	Seeds, Leaves	Wildfowl, Waterfowl
Ilex cassine	Fruit	Overwintering songbirds, Turkey, Grouse, Quail, Small mammals
	Browsing	White-tailed deer
Ilex decidua	Food	Winter songbirds, Upland gamebirds, Large & small mammals
	Grazing	Hoofed browsers
Ilex glabra	Food	Turkey, Bobwhite, Common flicker, Hermit thrush, Eastern bluebird, Cedar waxwing, Rufous-sided towhee, Waterfowl, Large & small mammals
	Cover, Nesting, Food	Mockingbird, American robin
Ilex verticillata	Berries, Food source	Mockingbird, Catbird, Brown thrasher, Hermit thrush, Cottontail rabbit, Raccoon, White-footed mouse, Squirrel, Ruffed grouse, Ring-necked pheasant
Iris sp.	Food	Muskrat, Wildfowl (probably not seeds), Marsh birds (Persists as cover under heavy grazing)
Itea virginica	Food, Cover	Waterbirds, Songbirds, Gamebirds, Small mammals
Iva frutescens	Cover, Nesting, Breeding	Red-winged blackbird, Roseate spoonbill
Juncus sp.	Food	Wildfowl, Upland game birds, Marsh birds, Song birds
	Bases, Roots	Muskrat (sparingly), Moose
	Spawning grounds	Rock bass, Bluegills, Other sunfish
Juncus effusus	Food, Cover, Nesting	Wood duck, other waterfowl
Juncus roemerianus	Cover, Nesting	Marsh wren
	Habitat	Muskrat
Laguncularia racemosa	Detritus - food	Many fish species
	Surface	Attached invertebrates, Oysters
	Nursery	Many fish species
	Harbors food	Wading birds

Table G-9: Wildlife Value ** (page 6 of 13)

Species Name	Benefits Provided	Which Species
Leersia oryzoides	Seeds	Many species of duck, Swamp and Tree sparrow, Sora rail
	Habitat for invertebrates (Food source)	Waterfowl, Rails, Herons, Other birds, and indirectly to raptors, herons, mammals, etc. that eat other consumers (such as fish, reptiles, or amphibians)
Lemna minor	Plants	Coot, Baldpate duck, Blue-winged teal, Mallard, Green-winged teal, Wood duck, Purple gallinule, Sora rail, Beaver
Leucothoe racemosa	Food	White-tailed deer
Limnobium spongia	Seeds	Waterfowl, Marsh birds
Lindera benzoin (Syn: *Benzoin aestivale*)	Food	Wood thrush, Veery, Ruffed grouse, Bobwhite, Ring-necked pheasant, Common flicker, Eastern kingbird, Great crested flycatcher, Gray catbird, American robin, Hermit thrush, Gray-cheeked thrush, Red-eyed vireo, Cardinal, White-throated sparrow, Wild turkey
	Twigs, Foliage (Browsing)	White-tailed deer
Liquidambar styraciflua	Food (Seeds)	Sparrow, Purple finch, Goldfinch, Junco, Redpoll, Pine siskin, Aquatic and terrestrial furbearers (e.g., Beaver)
Lobelia cardinalis	Nectar	Hummingbird, Oriole, Butterflies
Magnolia virginiana	Seeds	Towhee, Red-eyed vireo, Red-cockaded woodpecker, White-tailed deer, Gray squirrel
Monanthochloe littoralis	Habitat	California least tern, Light-footed clapper rail
Myrica cerifera	Fruit	Tree swallow, Meadowlark, Catbird, Bluebird, Myrtle warbler, Florida duck
Myrica pensylvanica	Food	Eastern meadowlark, White-eyed vireo, Yellow-rumped warbler, Tree swallow, Red-winged blackbird
Nasturtium officinale	Food	Waterfowl, Beaver, Muskrat, Deer, Trout, (Sometimes available all winter)
	Cover	Fish, Other small aquatic life
Nelumbo lutea	Seeds	Waterfowl, Marsh birds, Song birds
	Rhizomes	Aquatic furbearers (Beaver)
	Cover, Food	Fish
Nuphar luteum	Seeds	Ringnecked duck, Wood duck, Florida duck
	Plants	Beaver, Porcupine, Deer, Muskrat
	Shade, Shelter, Leaves harbor insects	Fish
Nymphea odorata	Stems, Roots, Seeds	Sandhill crane, Redhead & Canvasback duck
	Plants	Beaver, Muskrat, Porcupine, Moose, Deer

Table G-9: Wildlife Value ** (page 7 of 13)

Species Name	Benefits Provided	Which Species
Nyssa aquatica	Fruit	Turkey, Woodchuck, Robin, Mockingbird, Thrush, Thrasher
	Twigs & Foliage	White-tailed deer
Nyssa sylvatica	Food (fruit)	Wood duck, Common flicker, Cedar waxwing, Summer tanager, Red-headed woodpecker, Wood thrush, Robin, Pileated woodpecker, Aquatic furbearers, Terrestrial furbearers, Deer
	Hollow trunks	Raccoon, Owl
Onoclea sensibilis	Leaves	Upland gamebirds, Mammals (Varying hare, deer)
Osmunda sp.	Leaves	Upland gamebirds, Mammals (Varying hare, deer)
Panicum hemitomon	Seeds	Baldpate & Florida duck, Green-winged teal, White-fronted goose, Snipe, White-footed mouse
Panicum virgatum	Seeds, Young foliage	Florida duck, Teals, White-fronted goose, Snow goose, Baldpate duck
	Seeds	Spipes, Gound dove, Quail, Wild turkey, Red-wing blackbird, Cowbird, Blue Grosbeak, Longspurs, Pyrrhuloxia, Sparrows (Tree, Savannah, Lincoln, etc.), White-footed mouse
	Plants	Muskrat, Rabbit, Deer
Peltandra virginica	Seeds	Wood duck, Rail, Other birds
	Rootstocks NOT eaten	Geese, Muskrat
Phalaris arundinacea	Food, Cover	Prairie vole, Birds
	Nesting	Marsh wren, Red-winged blackbird
	Brood cover	Wood duck
Phragmites australis	Cover	Upland gamebirds, Songbirds, Marshbirds, Shorebirds, Aquatic furbearers, Terrestrial furbearers
	Low food value	
Picea sitchensis	Buds, Needles	Ruffed grouse
	Cones	Squirrels
	Fallen seeds	Chipmunks, Mice, Shrews, Seed-eating birds
Pinus rigida	Sprouts, Seedlings	White-tailed deer, Rabbits
	Seeds	Pine warbler, Pine grosbeak, Black-capped chickadee
Pinus serotina	Foliage (Cover)	Various birds
	Seeds	Rodents and various birds

Table G-9: Wildlife Value ** (page 8 of 13)

Species Name	Benefits Provided	Which Species
Pinus taeda	Seeds	Squirrels, Chipmunks, Mice, Other rodents, Bobwhite, Quail, Wild turkey
Platanus occidentalis	Food (Seeds)	Songbirds, Terrestrial furbearers, Aquatic furbearers
	Dens	
Platanus racemosa	Nesting	
	Minor as a food source	
Polvgonum hydropiperoides	Food	Northern pintail, Wild turkey
	Brood cover	Wood duck
	Habitat for invertebrates (Food source)	Waterfowl, Rails, Herons, Other birds, and indirectly to raptors, herons, mammals, etc. that eat other consumers (such as fish, reptiles, or amphibians)
Polygonum pensylvanicum (Annual)	Food, Cover	Wood duck, Northern pintail, American black duck, Other waterfowl, Wild turkey
Polygonum persicaria (Annual)	Cover and High food value (Seeds)	Songbirds and gamebirds (Wild turkey)
	Rhizomes	Rice rat, Canada goose
Polygonum punctatum	Food (Seeds)	Waterfowl, Marshbirds, Shorebirds, Upland gamebirds, Songbirds, Aquatic furbearers, Small mammals
Pontederia cordata	Seeds	Mottled duck, Other waterfowl
Populus balsimifera	Leaves & Young shoots	Game mammals
(Syn: *P. trichocarpa*)	Buds, Flowers, Seeds	Grouse, Quail, Songbirds
Populus deltoides	Buds & Catkins (food)	Ruffed grouse, Upland gamebirds, Songbirds, Waterfowl
	Buds	Evening grosbeak, Purple finch
	Sap	Yellow-bellied sapsucker
	Bark, Foliage	Aquatic furbearers, Terrestrial furbearers, Small mammals, Hoofed browsers
Populus fremontii	Twigs, Foliage	Mule deer, Beaver
Potamogeton diversifolius	Seeds, Plants	Coot, Canvasback, Trumpeter swan, Mallard, Redhead, Ring-necked duck, Avocet, Godwit, Pintail, Teals, Baldpate, Gadwall, Goldeneye, Ruddy duck, Scaups, Shoveller, Wood duck, Whistling and Canada goose
Potamogeton nodosus	Roots	Diving ducks
(Syn: *P. americanus*)	Seeds	Marsh ducks
	Habitat	Fish

Table G-9: Wildlife Value ** (page 9 of 13)

Species Name	Benefits Provided	Which Species
Potamogeton pectinatus	Seeds, Rhizomes (Highly nutritious), Leaves, Stems	Many species of duck (Most important pondweed for ducks, especially diving ducks), goose, and swan; Muskrat
	Food, Shelter	Amphibians, Reptiles, Fish, and Mammals
	Habitat	Invertebrates
Potamogeton perfoliatus	Food	Redhead duck, Canvasback duck, Mallard, Ring-necked duck, Black duck, Canada goose, Tundra swan
	Habitat	Aquatic organisms
Quercus bicolor	Food (Acorns, Buds)	Waterfowl (esp. Wood duck), Marshbirds, Shorebirds, Upland gamebirds, Songbirds (esp. Grackle, Blue jay, Brown thrasher, Red-bellied woodpecker, Red-headed woodpecker), Raccoon, Tree squirrel, Eastern chipmunk, White-footed mouse
Quercus lyrata	Food	Numerous overwintering waterfowl
Quercus nigra	Cover, Nesting	
	Acorns	Mammals (Gray squirrel), Wood duck
Quercus nuttallii	Acorns	Waterfowl
Quercus palustris	Food	Wood duck, Mallard, Quail, Wild turkey, Ruffed grouse, Bobwhite, Blue jay, Brown thrasher, Rufous-sided towhee, Deer, Fox, Opossum, Raccoon
	Cover, Nesting	Scarlet tanager, Rose-breasted grosbeak
Quercus phellos	Food, Cover, Nesting	Wood duck, Mallard, Quail, Wild turkey, Deer, Fox, Opossum, Raccoon, Common grackle, Ruffed grouse, Green-winged teal, Red-bellied woodpecker
Rhizophora mangle	Detritus - food	Many fish species
	Surface	Attached invertebrates, Oysters
	Nursery	Many fish species
	Harbors food	Wading birds
Rosa palustris	Food	Turkey, Mockingbird, Gray catbird, Brown thrasher, American robin, Wood thrush, Swainson's thrush, Eastern bluebird, Cedar waxwing, White-tailed deer
	Buds	Ruffed grouse, Bobwhite, Ring-necked pheasant
	Cover, Food	Cardinal, Northern junco, Tree sparrow, Fox sparrow, Song sparrow
Rubus sp.	Food	White-tailed deer, Wild turkey, Raccoon, Beaver, Pileated woodpecker

Table G-9: Wildlife Value ** (page 10 of 13)

Species Name	Benefits Provided	Which Species
Rumex verticillatus	Seeds	Cinnamon teal; Ruffed grouse; Redwing blackbird; Hoary redpoll; Grasshopper, Song, Swamp, Tree, and White-crowned sparrows
	Leaves, Plants	Cottontail rabbit, Deer
Ruppia maritima	Food (Rhizomes)	Waterfowl, Marshbirds, Shorebirds, Fish, Invertebrates
	Shelter, Nursery	Fish, Invertebrates
Sagittaria graminae	Food	Crayfish, Mallard, Pintail, Mottled duck,Other waterfowl, Nutria, Swamp rabbit, Beaver
Sagittaria latifolia	Seeds, Rhizomes, Plants	Canvasback duck, Gadwall duck, Trumpeter swan, Whistling swan, Black duck, Mallard, Pintail duck, Ring-necked duck, Scaups, Rails, Muskrat, Beaver
Sagittaria platyphylla	Cover	
(Syn: *S. graminae var. platyphylla*)	Food (Tubers & Seed)	Mallard, Pintail, Mottled duck, Other waterfowl
Sagittaria rigida	Seeds, Rhizomes, Plants	Waterfowl, Aquatic furbearers (Beaver)
	Seeds	Marshbirds, Shorebirds
Salicornia virginica	Cover	Saltmarsh harvest mouse, Shrew
	Nesting	Light-footed clapper rail, Belding's Savannah sparrow, California clapper rail, Black rail
Salix sp.	Food	Deer, Beaver, Squirrel, Hare, Rabbit, Moose, Porcupine, Muskrat, Other small game, Songbirds, Waterfowl, Marsh birds, Upland game birds
Salix laevigata (Syn: *S. bonplandiana*)	Food	Goldfinches, Yellow warblers, Long-tailed chats
Salix lasiolepis	Foliage	Mule deer
Salix nigra	Buds	Ruffed grouse, Pine grosbeak, Waterfowl, Small mammals
	Cover, Nesting	Red-bellied woodpecker, Common redpoll
Sambucus canadensis	Food	Red-bellied woodpecker, Red-headed woodpecker, Pileated woodpecker, Brown thrasher, Wood thrush, Yellow-breasted chat, Cardinal, Eastern bluebird, Wild turkey, Bobwhite quail, Mourning dove, Chipmunk, White-footed mouse, Raccoon, Woodchuck
	Cover, Nesting	Alder flycatcher, Gray catbird, Yellow warbler, American goldfinch, Mourning dove, Ring-necked pheasant
	Twigs, Leaves	Hoofed browsers
Saururus cernuus	Food	Wood duck

Table G-9: Wildlife Value ** (page 11 of 13)

Species Name	Benefits Provided	Which Species
Scirpus sp.	Cover, Seeds, and/or rootstocks	Coot; Baldpate, Black, Canvasback, Gadwall, Mallard, Mottled, Pintail, Redhead, Ring-necked, Ruddy, Greater scaup, Lesser scaup, Shoveller, Blue-winged teal, Cinnamon teal, and Green-winged teal ducks; Canada, Tule, and Snow or Blue geese; Trumpeter swan; Sandhill crane; Long-billed dowitcher; Hudsonian godwit; Sora & Virginia rails; Semipalmated sandpiper; Snipe; Mearn's quail; Muskrat; Fish
	Nesting	Bluegills, Largemouth black bass
Sesuvium portulacastrum	Cover, Nesting	
	Low food value	
Sparganium americanum	Seeds	Mallard, Wood, Canvasback, Ring-necked, and Teal ducks, Scaups, Whistling swans, Muskrats, Beaver
	Plants	Muskrat, Canada goose
Sparganium eurycarpum	Seeds	American black duck, Wood duck, Other waterfowl, Beaver
	Plants	Muskrat, Canada goose
Spartina alterniflora	Seeds, plant parts, and rootstocks	Black duck; Canada, and Snow or Blue goose; Rails; Seaside and Sharp-tailed sparrow; Muskrat
Spartina cynosuroides	Seeds, rootstocks	Black duck; Canada, and Snow or Blue geese; Rails; Seaside and Sharp-tailed sparrow; Muskrat
Spartina foliosa	Food, Cover	Light-footed clapper rail
Spartina patens	Rootstocks, Seeds	Canada, and Snow or Blue geese, Black duck, Sparrows, Rails
Spartina pectinata	Food	American black duck, Other waterfowl
	Nesting	Marsh wren
	Habitat	Muskrat
Spirodela polyrhiza	Plants	Coot, Baldpate duck, Blue-winged teal, Mallard, Green-winged teal, Wood duck, Purple gallinule, Sora rail, Beaver
Symplocarpus foetidus	Fruit, Leaves	Upland gamebirds (Ring-necked pheasant)
Taxodium distichum	Perching site, Nesting (Hollow trunks)	
(*Taxodium ascendens* is similar)	Cypress swamps provide cover	Many species
	Seed	Sandhill crane

Table G-9: Wildlife Value ** (page 12 of 13)

Species Name	Benefits Provided	Which Species
Thalassia testudinum	Food	Sea turtles, Many species of waterfowl
	Shelter, Food, Nursery	Scallop, Shrimp, Lobster, Grouper
	Concentrate food sources	Heron, Egret, Spoonbill, Cormorant, Pelican
Thelypteris sp.	Leaves	Upland gamebirds, Mammals (Varying hare, deer)
Thuja occidentalis	Buds	Red squirrel
	Browse	Snowshoe hare, White-tailed deer, Moose
	Seeds	Pine siskin
Thuja plicata	Cover	Squirrel, Grouse, Smaller birds
Typha angustifolia	Seeds, rootstocks	Tule and Snow or Blue geese; Teal duck; Muskrat, Beaver
	Cover, Nesting	Canvasback duck, Western grebe, Marsh wren, Red-winged blackbird, Wood duck, Gadwall, Young fish
	Spawning grounds	Sunfish
Typha latifolia	Seeds, Rootstocks	Tule and Snow or Blue geese; Teal duck; Muskrat, Beaver
	Cover, Nesting	Canvasback duck, Western grebe, Marsh wren, Red-winged blackbird, Wood duck, Gadwall
Ulmus americana	Seeds	Ruffed grouse, Purple finch, American goldfinch, Wood duck, Cardinal, Yellow rumped warbler
	Cover, Nesting	Common flicker, Red-bellied sapsucker, Red-eyed vireo, Northern oriole, Black-capped chickadee
	Food	White-tailed deer, Fox squirrel, White-footed mouse, Beaver
Vaccinium corymbosom	Berries	Tufted titmouse, Brown thrasher, Eastern bluebird, Orchard oriole, Bobwhite quail, Wild turkey, Mourning dove, Black bear, Fox, Skunk
	Plant parts	Red fox, Skunk, Deer, Chipmunk, Mice
	Cover, Nesting	Eastern kingbird, Gray catbird, Rufous-sided towee, Ruffed grouse, Cottontail rabbit
Vallisneria americana	Food	Canvasback, Redhead, Lesser scaup, Mallard, Swan, Wigeon
	Habitat	Fish, Aquatic invertebrates
	Shade, Shelter, Supports insects, Food	Fish
Vallisneria spiralis (cont'd)	Food	Bluebills, Redheads, Canvasback, Wood duck, Wigeon, Pintail, Ruddy, Bufflehead, Whistler, Teal, Scoter, Mallard, Black duck, Goose, Swan, Coot

Table G-9: Wildlife Value ** (page 13 of 13)

Species Name	Benefits Provided	Which Species
V. spiralis (cont'd)	Habitat	Fish
Viburnum dentatum	Food	Small mammals, Ruffed grouse, Common flicker, Eastern phoebe, Brown thrasher, American robin, Pileated woodpecker
	Cover, Nesting	Gray catbird
Viburnum lentago	Food	Bobwhite, Ring-necked pheasant, Cedar waxwing, Rose-breasted grosbeak, Purple finch, Pileated woodpecker
	Cover, Nesting	Gray catbird, Hermit thrush
Viburnum trilobum	Emergency food	Gamebirds, Songbirds (Preferred by Waxwings) & Small mammals in winter, Pileated woodpecker
Woodwardia areolata	Leaves	Upland gamebirds, Mammals (Varying hare, deer)
Zizania aquatica (Annual)	Nesting	Marsh wren
	Seeds; Plant parts, and Rootstocks	Wood duck, American black duck, Other waterfowl, Muskrat, Red-winged blackbird, Rail, Bobolink
Zizaniopsis miliacea	Food, Cover, Nesting, Breeding	
	Foliage, Seed	Mallards, Black duck, Shoveler duck, Ringneck, Small animals
Zostera marina	Food (Rootstocks)	Black brant, American brant, Canvasback duck, Pintail, American wigeon, Clam, Oyster, Beaver
	Shelter, Nursery, Food	Invertebrates, Fish
	Detritus	Invertebrates eat bacteria on seagrass

** **NOTE:** Lists of animal species which use the plants in this table are not exhaustive. Information regarding other animals which use the plants may not be available. While it is possible to determine from this table which plants are of high value according to the number and diversity of species that benefit from each plant, it should not be assumed that a plant is of low value because only a few animals or benefits are listed. Plants known to be of low value to wildlife are so noted.

TABLE G-14

SEED INFORMATION FOR WETLAND PLANT SPECIES (page 1 of 3)

Plant Species [1]	Seeds/Pound [2]	Storage [3]	Dormancy [4]	Lifetime [5]	Success of Seeding
Agrostis alba (FACW)	500,000	dry	unknown	unknown	field
Andropogon glomeratus [6] (FACW+)	3,200,000	dry[7]	yes	> 1 year	nursery
Andropogon virginicus [8] (FACU)	2,900,000	dry[7]	yes	> 1 year	nursery
Asclepia incarnata (OBL)	50,000	dry	no	unknown	nursery
Aster novi-belgi [6] (FACW+)	4,600,000	dry	no	> 1 year	nursery
Baccharis halimifolia (FACW)	8,600,000	dry	no	unknown	nursery
Bidens polylepis (FACW)	130,000	dry	no	> 2 years	field & nursery
Cephalanthus occidentalis (OBL)	96,000[9]	dry	no	>10 years	nursery
Distichlis spicata (FACW+)	1,400,000	dry	yes	> 2 years	nursery
Eryngium aquaticum (OBL)	1,300,000	dry[7]	yes	> 1 year	nursery
Eupatorium dubium [6] (FACW)	1,200,000	dry[7]	no	> 1 year	nursery
Hibiscus moscheutos (OBL)	45,000	dry	no	> 6 years	nursery
Impatiens capensis (FACW)	49,000	dry[7]	yes	unknown	nursery
Iris pseudocorus (OBL)	7,900	dry/wet	no	> 6 years	nursery
Iris versicolor (OBL)	18,000	dry	no	> 1 year	nursery
Iva fructescens (FACW+)	320,000	dry	no	unknown	nursery
Juncus romerianus (OBL)	6,500,000[10]	dry	no	unknown	nursery

TABLE G-14

Plant Species [1]	Seeds/Pound [2]	Storage [3]	Dormancy [4]	Lifetime [5]	Success of Seeding
Kosteleskia virginica (OBL)	23,000	dry	no	> 3 years	nursery
Leersia oryzoides (OBL)	610,000	dry	yes	> 6 years	field & nursery
Lobelia cardinalis (FACW+)	5,100,000	dry	no	> 3 years	nursery
Panicum virgatum (FAC)	310,000	dry	no	> 4 years	field & nursery
Peltandra virginica (OBL)	500 (moist)	moist	yes	> 1 year	field & nursery
Pluchea purpurascens [6] (OBL) (annual)	4,100,000	dry	no	> 1 year	nursery
Polygonum pennsylvanicum (FACW) (annual)	62,000	dry	no	> 1 year	nursery
Polygonum densiflorum (OBL)	110,000	dry	no	unknown	nursery
Pontederia cordata (OBL)	5,000 (moist)	water	no	> 3 years	nursery
Sabatia campanulata (FACW)	15,000,000	dry	no	> 2 years	nursery
Sagittaria latifolia (OBL)	940,000	dry	no	> 3 years	nursery
Saururus cernuus (OBL)	600,000[11]	dry	no	> 7 years	nursery
Scirpus cyperinus [6] (FACW+)	16,000,000	dry	no	> 2 years	nursery
Scirpus pungens [12] (FACW+)	220,000	dry[13]	no	> 4 years	field & nursery
Scirpus robustus (OBL)	170,000	dry[7]	no	> 3 years	field & nursery
Scirpus validus (OBL)	540,000	dry[7]	yes	> 2 years	nursery

TABLE G-14
(page 3 of 3)

Plant Species [1]	Seeds/Pound [2]	Storage [3]	Dormancy [4]	Lifetime [5]	Success of Seeding
Solidago sempavirens (FACW)	6,400,000	dry	no	unknown	nursery
Spartina alterniflora (OBL)	130,000 (moist)	40 ppt salt water	yes	1.5 years	field & nursery
Spartina cynosuroides (OBL)	240,000 (dry)	dry or water [13]	yes	> 2 years	field & nursery
Spartina patens (FACW+)	770,000	dry	yes	> 4 years	nursery
Typha angustifolia [6] (OBL)	14,000,000	dry	no	> 2 years	field & nursery
Typha latifolia [6] (OBL)	14,000,000	dry	no	> 2 years	field & nursery
Vernonia voveboracensis [6] (FACW+)	350,000	dry[7]	no	> 1 year	nursery
Verbena hastata (FACW+)	690,000	dry	no	> 1 year	nursery

[1] All species are perennial unless otherwise indicated. Wetland indicator status of species is provided in parentheses.[2] Seeds were air dried for three days before sampling in triplicate. Although all seeds are pure, the weights are not of seeds that only contain embryos, when this could be determined (i.e., for grasses). Numbers are rounded off at the second digit from left to right. Seed stored moist or in water was weighed moist, with all surface water removed. [3] Storage is at 34 - 40° F. [4] Cold storage is required to break dormancy. Evidence of dormancy is significantly increased germination percentage (and generally seedling vigor) as a function of time under cold storage. [5] Time that seed viability is maintained under storage. [6] Pappus was not separated from seed. Consequently, the weight given is that of seed plus pappus. [7] Seed stored cold in moist peat enhances germination percentage. [8] This species is found to adapt to continued culture in saturated soils. [9] Capsules (nutlets or fruits) per pound. Each capsule contains two seeds. [10] Seeds are contained in capsules (nutlets or fruits). [11] Seeds are contained in capsules. Each capsule contains four seeds. [12] Formerly *Scirpus americanus*.. [13] Cold storage in water for several months leads to accelerated germination.

APPENDIX H
COST ESTIMATING

H.1 INTRODUCTION

Appendix H provides an overview of the cost categories that need to be considered for wetland replacement projects. Table H-1 summarizes potential wetland cost categories which may apply to most wetland replacement projects. Actual detailed costs or cost estimating procedures are not included, however, because of the many highly variable factors which can affect costs, including

- Geographic location of the site
- Prevailing labor costs for a region
- Depth of excavation
- Material costs
- Special studies required during design
- Number of sites considered during the site selection process and data collection requirements to confirm the feasibility of the selected site
- Land acquisition costs

Also, not included here is a discussion of costs associated with the applicable wetland permit process, which will be above and beyond costs incurred for wetland replacement. These additional costs can be significant.

Experience to date indicates that the cost of a wetland replacement project is frequently underestimated because costs–per–acre estimates are quoted for certain portions of the project, i.e., grading and planting. Frequently, these cost estimates do not incorporate up-front planning costs, including:

- Initial impact evaluations of the existing wetland occurring during the early stages of project planning
- Location and site selection and feasibility studies performed during project engineering
- Conceptual and design plan costs and special site investigations necessary to complete the wetland replacement design

Generally, however, the costs of the studies needed to prepare correct plans and specifications are usually small compared to the overall project costs. As a result, costs often are not tracked as carefully as other aspects of the project. The wetland replacement costs often are lumped into broad categories—such as "environmental" or "miscellaneous"—so that the actual cost of the wetland replacement project is difficult to ascertain.

A description of each of the cost categories presented in Table H-1 and factors under each which will affect the wetland replacement costs follow.

H.2 COSTS TO BE CONSIDERED IN THE WETLAND REPLACEMENT PROCESS

H.2.1 EVALUATION OF IMPACTED WETLAND

The wetland that will be lost to the proposed project should be evaluated (Chapter 1 and Appendix J) to establish what functions it performs. This information will then be used to help establish the goals and objectives of the replacement wetland. Depending on the size and complexity of the wetland to be impacted, the assessment could be simple and straightforward, or it could entail a significant amount of field evaluation.

On small and/or straightforward sites, one day in the field may be all that is necessary to evaluate the site using best professional judgment and/or the Wetland Replacement Evaluation Procedure (Appendix J). On more complex sites, several days may be needed to evaluate such items as tree size and species distribution, or vegetation type/habitat/open water ratios, and then to map these data. In addition, endangered or threatened species surveys may be required by the regulatory agencies.

H.2.2 LOCATION OF POTENTIAL REPLACEMENT SITES

Locating potential wetland replacement sites can be a time–consuming process. Finding existing data (i.e., tax maps, topographic maps, aerial photography) from a variety of sources may take several hours to several days, and their purchase can be expensive. Some municipalities may have only one or two tax maps available for public review, and these documents may only be available to the public at the municipal offices during certain hours of the week. Such time constraints and data availability can add substantially to the consulting hours needed to complete the task.

After the office level review of the data is completed, the initial candidate sites must be visited as part of the site selection process. Generally the "windshield-level" assessment of the sites should take no longer than one day, but inaccessibility or remoteness of the sites could extend the amount of time needed to field-check them quickly.

The candidate sites remaining after the "windshield-level" assessment should be field-evaluated. This entails a site visit to each location. Photographs of the sites may be needed as well as the collection of some field data. In addition to the actual time needed for site inspections, considerable time may be needed to learn who owns the properties and to request and receive their permission to enter the sites.

Depending on the hydrology of the proposed replacement wetland, detailed hydrologic calculations may be needed (Appendix E). These calculations require time and, in many cases, the services of a hydrologist. Additional time should also be budgeted to make the final site selection and to have a progress meeting with the entire wetland replacement team. (Chapter 2 contains detailed information on the site selection process.)

TABLE H-1

CATEGORIES OF POTENTIAL WETLAND REPLACEMENT COSTS

✓ **SETTING GOALS AND OBJECTIVES**

- ❒ Assessment of wetland to be impacted

✓ **SITE SELECTION**

- ❒ Collection of existing data (e.g., tax maps, NWI maps, soil surveys, etc.)
- ❒ Analysis of existing data
- ❒ Analysis of several candidate sites
- ❒ Determination of property ownership
- ❒ Biological benchmarks

If wetland is present:

- ❒ Wetland delineation
- ❒ Wetland assessment

Hydrology:

- ❒ Hydrologic studies
  - ▫ Monitoring wells and monitoring
  - ▫ Stream gauges and/or flow meters and monitoring
- ❒ Hydrologic calculations
- ❒ Water quality studies

Soils:

- ❒ Subsurface investigations
- ❒ Infiltration studies
- ❒ Chemical analysis
- ❒ Engineering studies

✓ **SURVEYS**

- ❒ Metes and bounds
- ❒ Topographic
- ❒ Wetland boundary

✓ **LAND COSTS**

- ❒ Land acquisition
- ❒ Legal services
  - ▫ Land acquisition
  - ▫ Condemnations
  - ▫ Easements

TABLE H-1

CATEGORIES OF POTENTIAL WETLAND REPLACEMENT COSTS (continued)

✓ **CONCEPTUAL PLANS**

- ❒ Plans and notes

✓ **MEETINGS**

- ❒ Design team
- ❒ Regulatory agencies
- ❒ Public hearings

✓ **FINAL DESIGN**

- ❒ Planting plans and specifications
- ❒ Grading plans and specifications
- ❒ Sediment and erosion control plans and specifications
- ❒ Details and cross sections of important structures, for example:
  - Weirs
  - Channels
  - Dams and dikes
  - Water control structures
  - Fish and wildlife attractors

✓ **CONSTRUCTION**

- ❒ Excavation and disposal of soils
- ❒ Design features, for example:
  - Dams or dikes
  - Water control structures
  - Exclosure fencing
  - Channels
- ❒ Planting
- ❒ Construction supervision

Materials:

- ❒ Construction materials (riprap, culverts, water control structures, wildlife attractors)
- ❒ Plant material

✓ **MAINTENANCE**

- ❒ Watering
- ❒ Control of invasive vegetation or problem animals
- ❒ Debris removal
- ❒ Repairs

✓ **MONITORING**

- ❒ Site visits
- ❒ Report preparation

H.2.2.1 Subsurface Soil Investigations

Soil characteristics at and below the proposed final grade will have to be ascertained. Information on particle size distribution as well as the presence of pyritic materials at the final design elevations will help to determine the suitability of the site. This information will also help to determine whether soil amendments will be needed. If the final design elevation is shallow, this information can often be collected with a hand auger, but if the final design elevations are much below 4 feet, a power drilling rig may be required.

H.2.2.2 Surveys

A topographic survey of the site at one- to two-foot contours is needed so that accurate cut and fill measurements can be completed and cost estimates can be calculated. A wetland delineation may have to be conducted on the replacement site to determine available acreage for replacement. Metes and bounds surveys on the replacement site may also be needed. In addition, under many circumstances, biological benchmarks may have to be established (Chapter 2).

H.2.2.3 Land Acquisition

The cost to purchase the appropriate amount of land for the site and any required buffers (Chapter 2.5.6) can be a significant project cost. If the landowner is not a willing seller, then the added cost of condemnation proceedings must be considered. Legal fees for land acquisition and possibly deed restrictions on the replacement wetland and buffers (Appendix B) will also add to the project costs.

H.2.3 CONCEPTUAL WETLAND REPLACEMENT PLAN AND REPORT

Generally, only one conceptual plan will need to be submitted to the regulatory agencies. Under some circumstances, several may be developed and reviewed by the wetland replacement team before the best plan is chosen and submitted to the agencies. A conceptual plan can take between ten to twenty hours to draft. The design of the plan and the preparation of the report that accompanies the conceptual plan may take an additional ten to twenty hours to complete.

A minimum of two meetings will also be required during this stage of the project. The first meeting is to familiarize the wetland replacement team with the concept and discuss any outstanding issues. The other meeting will be a site visit with the regulatory agencies to familiarize their representatives with both the proposed wetland impact site and the proposed wetland replacement site.

Under some circumstances, substantial time may be needed to coordinate the interagency meeting and responses to agency comments. The agency comments may necessitate redrafting the conceptual plan, or even beginning the site selection process all over again. (Chapter 3 discusses in detail the development of a conceptual mitigation plan.)

H.2.4 COLLECTION OF ADDITIONAL INFORMATION

After determining that the site will support the replacement wetland and the conceptual plan has been approved by the regulatory agencies, some additional information may be needed to complete the final plans and specifications.

The hydrology proposed for the replacement wetland will determine what studies are needed and for what duration. Biological benchmark information may be all that is required in tidal systems. For groundwater–driven systems, monitoring wells will have to be installed and monitored at least once and preferably twice a month, ideally for a year. In some instances, continuous chart recorders may be necessary to document the fluctuations in the groundwater elevation. If the system will be driven by river or streamflow above baseflow, stream gauge and volume recorders may be needed. The cost to rent these monitoring devices must be estimated in the replacement wetland budget, along with the field time needed to collect the data, analyze it, and correlate it with other existing data such as seasonal rainfall. (Chapter 4 and Appendix E contain a detailed discussion on hydrology.) Under some circumstances water quality studies may be needed as well.

If dams, dikes, or other structural components are part of the conceptual plan, then soil engineering studies may also be needed. The suitability of the existing soils for such structures must also be determined. (Appendix F contains a detailed discussion of soils.)

Other information that may be needed includes (Chapter 4):

- Wildlife surveys to determine whether wildlife populations in the area may cause damage to the replacement site—this usually entails contacting game wardens for local information
- Assessment of whether human impact to the site will be significant
- Seed bank studies

All of these tasks require time, and a seed bank study requires controlled experimental conditions.

H.2.5 FINAL DESIGN

After the studies have been finished and the data analyzed, if the site proves to be feasible, then the final design of the replacement wetland can be completed. Under most situations several plan sheets will be required. The grading plan and the details of the sediment and erosion control plan will have to be drafted. In some jurisdictions, the sediment and erosion control plan must be signed and sealed by a professional engineer. Planting plans also have to be drafted. Engineering of structures (i.e., weirs, check dams, dikes) that are part of the replacement project must be designed. In addition to drafting, specifications will have to be written for all plan sheets (Chapter 5).

Several meetings of the wetland replacement team may be needed to complete the design, and then an interagency meeting should be arranged to review the plans. Time should also be budgeted to coordinate agency comments on the plans and revisions made from those comments.

H.2.6 CONSTRUCTION

The costs associated with constructing a replacement wetland are usually a significant portion of the overall replacement project. Many are typical of construction expenses, such as mobilization and demobilization, and implementing the sediment and erosion control plan. Generally, the costs associated with site clearing, wood chipping, and disposal of materials on a wetland replacement project are equivalent to those on a highway construction project.

Other costs are not necessarily equivalent. Grading could be substantially more expensive on a cubic-yard basis than for a typical construction project because grading specifications on a wetland replacement plan are fairly tight, usually on the order of ± 0.2 feet. This tight grading specification is needed to ensure that the hydrology is properly established and that plants will be installed at the appropriate elevations. Obviously, the fine grading required on a wetland replacement project will take more time than on a coarse grading project.

If the excavated material cannot be used on the project, its disposal will be an added expense. Trucking costs to the nearest disposal site, as well as the potential for tipping fees, must be considered.

Plant costs may be higher than those generally associated with nursery stock because:

- Fewer nurseries carry wetland plant stock, thus reducing competitive pricing.
- Cultivation of many wetland plant species is more labor intensive than other plant species.
- Prior to installation, some plants may have to be acclimated to the hydrologic or salinity regime of the replacement site.

Installation of wetland plant materials will not necessarily be equivalent to the costs generally associated with landscaping. It should not be assumed that standard landscaping formulas (i.e., total cost = three times the plant costs) will generate an accurate estimate of planting costs on a wetland replacement project.

In some instances, plants will have to be installed in water, substantially increasing the time it takes to plant them. In other cases, they will have to be installed by hand instead of by tractor-mounted power augers because site conditions will not support planting machinery. Costs of pumping water from a site to prepare for planting must also be calculated in the planting costs. Planting in the dry is usually more cost-effective than planting in the wet (Appendix G.6).

Although cost estimates for installing plants cannot be reasonably discussed in this appendix because of the wide variability in labor costs nationwide, the typical staff hours generally needed to install wetland plant material are listed in Table H-2.

TABLE H-2

APPROXIMATE HOURS FOR INSTALLATION OF WETLAND PLANT MATERIAL

Item To Be Planted	Number Planted per Man Hour
Peat pots or bare–rooted (dry planting)	125
Peat pots or bare–rooted (wet planting)	40
Trees and shrubs (with auger and tractor)	7
Trees and shrubs (by hand)	4

H.2.7 MAINTENANCE

Maintenance of the wetland replacement site is another budget consideration. Plants may have to be watered the first year for proper establishment, particularly when the replacement wetland is designed to be a seasonally flooded wetland (Chapter 7). Often these replacement types may be subject to drought conditions which may adversely impact vegetation establishment. Removal of water– or wind– borne debris that might smother newly established plants may be required for the first couple of years. In northern climates, water may have to be drawn down the first winter to prevent ice sheets from pulling newly established plants from the ground before they establish strong root systems. Repair of vandalized structures and/or animal damage may be required, along with controls for nuisance animals or plants (Appendix I).

H.2.8 MONITORING

Monitoring of the replacement wetland may be required as part of the permit conditions. The monitoring may require one or more site visits per year and the preparation and submittal of a findings report to the regulatory agencies (Chapter 8).

H.3 WETLAND CONSTRUCTION COSTS

The most comprehensive study completed to date on the cost of wetland construction is by King and Costanza (1994). They developed complete engineering-cost-accounting profiles of over 90 wetland projects. To compile the data, they reviewed over 1,000 wetland projects. They found costs to vary from $5 per acre to $1.5 million per acre. Cost differences relate to wetland type and site-specific factors affecting preconstruction, construction, and post-construction. For non-agricultural projects, site-specific factors have a much greater effect on project costs than wetland type.

H.3 REFERENCES CITED

Guinon, M. 1990. Project elements determining comprehensive restoration costs and repercussions of hidden and inaccurate costs, pp. 162–171. In H.G. Hughes and T.M. Bonnicksen (Eds.), Restoration 1989: The New Management Challenge. Proceedings of the First Annual Meeting of the Society for Ecological Restoration. Madison, Wisconsin.

King, D. and R. Costanza. 1994. Costs of Wetland Creation and Restoration—Final Report. Department of Energy, Washington, D.C.

APPENDIX I
PROBLEMS AND THEIR SOLUTIONS

In addition to the references cited at the end of this appendix, authors contacted the individuals listed below about their expertise on various wetland replacement topics. These contacts are noted in the text parenthetically as "(NAME personal communication)."

Garbisch, Edgar W., Environmental Concern, Inc., P.O. Box P, 210 West Chew Avenue, St. Michaels, MD 21663
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I.1 INTRODUCTION

As might be expected, there are both institutional and technical problems associated with the Wetland Replacement Process (WRP). Many of these problems can be avoided through their consideration in Steps 5 (preparation of construction plans and specification) and 6 (construction of the wetland replacement). Others are unavoidable because they cannot be anticipated or otherwise managed. Consequently, the two problem categories considered here are:

- **Avoidable problems:** those that can be averted by applying avoidance solutions in the construction plans and specifications and assuring that the project is constructed according to these plans and specifications.

- **Unavoidable problems:** those that normally can be solved only after the problem has arisen, and even then there are instances where they cannot be solved.

This appendix is intended as an overview of the problems that have been noted to date by the Research Team and others involved with wetland replacements. Users of the *Guidelines* who suspect there is a potential problem that is not discussed here should proceed as if their suspicion is correct and work on a solution. The problems discussed here are only a sampling of those that will be identified as the wetland replacement technology develops. However, anticipating these problems and those yet to come can aid in achieving successful wetland replacement projects. Table I-1 summarizes the avoidable and unavoidable problems and solutions included in this appendix.

Some of the specific problems listed in Table I-1 and discussed below can be placed in both problem categories. In such instances, the problem will be placed in the more likely problem category, and the other category will be mentioned.

Both corrective solutions (i.e., solving the problem at hand) and avoidance solutions (i.e., avoiding the problem before project implementation or in future projects) will be discussed when applicable. However, there will be instances where there are no corrective and/or avoidance solutions.

POTENTIAL PROBLEMS

Although a problem with mosquitoes has yet to be reported in a wetland replacement, it is one that will likely occur sometime.

Avoidable problems arise from improper design or not constructing the project according to plans and specifications.

TABLE I-1

AVOIDABLE AND UNAVOIDABLE PROBLEMS

Possible solutions are in sections listed		
Avoidable Problems		
❒	Institutional considerations	I.2.1
❒	Unstable site grades	I.2.2
❒	Development of stormwater erosion gullies	I.2.3
❒	Problems caused by physical structures	I.2.4
❒	Volunteering of site by invasive plant species	I.2.5
❒	Salt buildup in soils (brackish and salt marsh)	I.2.6
❒	Incorrect fertilization program	I.2.7
❒	Insufficient site hydrology	I.2.8
❒	Shading	I.2.9
❒	Planting at wrong elevations	I.2.10
❒	Planting the wrong species for the site hydroregime	I.2.11
❒	Unsuccessful seeding results	I.2.12
❒	Unsuccessful planting	I.2.13
❒	Improper sediments	I.2.14
❒	Poorly drained and anoxic sediments	I.2.15
❒	Unstable peat bank development	I.2.16
Unavoidable Problems		
❒	Unusual meteorological conditions	I.3.1
❒	Ice damage	I.3.2
❒	Litter and debris deposits	I.3.3
❒	Plant disease	I.3.4
❒	Vandalism	I.3.5
❒	Animal management and control	I.3.6

I.2 AVOIDABLE PROBLEMS AND THEIR SOLUTIONS

I.2.1 INSTITUTIONAL CONSIDERATIONS

Wetland replacement (creation), restoration, and enhancement combine to form an industry in the United States that is extremely young (less than 25 years old). Within the past few years, the number of firms actually involved in wetland mitigation has grown substantially. The Research Team believes the lack of experience by both the private and the public sector is an important reason why many projects have problems or ultimately fail.

Project sponsors and others usually require that wetland replacement plans and specifications be sealed by state licensed/registered landscape architects or civil engineers. The Research Team believes it is important to recognize about any endeavor that is highly specialized and in a developing field such as wetland mitigation that not everyone has had the prerequisite experience, even if he or she has been practicing in the field and/or is licensed. In general, project sponsors are encouraged to assemble experienced project teams and to prequalify members of the team based on applied project experience, reputation, education and training, and references, in addition to having the requisite license, if required.

PERSONNEL QUALIFICATIONS

Design teams for wetland replacement projects should be comprised of qualified team members. Contractors and/or subcontractors selected for replacement wetland construction projects should have demonstrated experience in wetland construction.

In addition, because of the specialized nature of wetland replacement, it is important that contractors selected to perform the work have documented experience in wetland construction and/or have subconsultants who are. The Team believes that a contractor's past experience on highway construction or other related projects does not necessarily mean that the person has the skills and experience to bid the job properly or to complete construction of the replacement wetland. The risks of failure on wetland projects can be fairly high, so selection of skilled, experienced contractors is important to ensure that the replacement project is constructed according to approved plans and specifications.

Avoidance solutions:

- Have all design work completed by a person with a history of successful wetland replacement design experience. If not possible, at least have such a person review it.

- Let separate wetland replacement contracts to contractors with a history of successful wetland replacement construction. If this is not practicable or otherwise possible, ensure that the construction is managed by a person(s) having a history of successful wetland replacement design and construction.

I.2.2 UNSTABLE SITE GRADES

To obtain the required wetland replacement acreage within the least total land acreage, side slopes from wetland to upland often are designed excessively steep. Subsequently, erosion on the slopes and shoreline at the land-water interface can become serious problems which detract from the functionality of the replacement wetland. If unchecked, such problems, over time, could cause the replacement wetland to fill in with eroded soils and result in alteration or loss of wetland function.

Project sponsors are familiar with the variety of possible corrective solutions to the problem, since they have established extensive design standards for stabilizing steep embankments. Such solutions probably would exclude regrading because of land acreage constraints, but they might involve reshaping the slope, followed by underseeding or planting through an appropriate geotextile material or placing stone armoring over appropriate geotextile material.

Avoidance solution:

- Do not design vegetated slopes that will be unstable because of steepness.

I.2.3 DEVELOPMENT OF STORMWATER EROSION GULLIES

Stormwater erosion gullies might form because of conditions discussed above. Their development may be unavoidable, arising from undetectable changes in grade caused by heavy equipment during site construction. Such erosion problems detract from the functionality of the replacement wetland and, if continued unchecked, could fill it in with eroded soils and cause a loss of wetland functions.

Corrective solutions:

- If erosion gullies are abundant, regrade the site to manage and direct the stormwater to one or several stone armored swales to convey the water to an appropriate discharge point.
- If the erosion gullies are few, stabilize them through enlargement and shaping, followed by lining with appropriately sized stone over filter fabric.

Avoidance solution:

- Design stormwater management for all wetland replacement projects so that stormwater is collected and conveyed to appropriate discharge point(s) without causing sediment erosion.

I.2.4 PROBLEMS CAUSED BY PHYSICAL STRUCTURES

Physical structures may lead to erosion and hydrologic problems if not properly designed. Some examples follow (Table I-2).

Avoidance solution:

- Recognize that structures can cause problems; design them to prevent these problems.

I.2.5 COLONIZATION OF SITE BY INVASIVE PLANT SPECIES

The presence of invasive plant species near the site is a potential problem. As the seeds of these species are often very small, they can be transported great distances through the air and on or in the water. Consequently, they pose a potential problem, even when such species are not near the site. Colonization of the replacement site by invasive plant species could negatively impact the goals and objectives of the project. In such instances, all efforts to avoid this problem should be taken during the project design.

Corrective solution:

- Remove/eliminate the undesirable species and replace them with desirable ones. For minor problems, this may involve hand removal of the individuals or wick application of herbicide on the individuals during scheduled maintenance work. If colonization is widespread, then large–scale herbicide application may be warranted, followed by re–planting of the desired species. The objective is to achieve full ground coverage by desirable plant species throughout the elevations to which the invasive species will adapt, so that there is little available space (and consequently, little opportunity) for the species to invade.

Avoidance solutions:

- Do not select a site in Step 2 (Site Selection) of the WRP if it is surrounded by invasive plant species.

TABLE I-2

EXAMPLES OF PROBLEMS ARISING FROM PHYSICAL STRUCTURES AND CORRECTIVE SOLUTIONS

Problem	Corrective Solution
Bulkheads and other near-vertical structures that are placed in the water may lead to scouring of bottom sediments along their toes due to the downward vector of energy from reflecting waves.	Place stone armoring along the toe of the bulkhead.
Groin systems typically will experience land erosion along their lee sides due to the change of the wave direction vector from angular to perpendicular to the shore as waves pass over.	Construct a stone revetment over filter fabric on the eroding land at the lee side of the groins.
Undersized culverts will detain water on site or lead to tidal restriction (for tidal hydrology) from the site which, in turn, may alter the hydrology to the degree that the specified vegetation is inappropriate for the specified elevations.	Replace undersized culverts with properly sized ones.
Improperly designed and constructed water conveyance structures may back up water and cause overflows over their sides, leading to erosion gullies or sediment erosion.	Replace the structures with properly sized ones for the existing water flows.
The energy of water discharged from culverts and other structures can lead to sediment erosion problems.	Construct a stone apron at the discharge point to dissipate energies.
Water control structures become clogged and site hydrology changes.	Clear structure and eventually replace with one that is more maintenance free.

- Design and specify dense vegetation coverage of all ground elevations at which the invasive species might become established. The greater the ground coverage by desirable species, the lower the opportunity for invasive species to colonize.

- Never specify that a site be left unvegetated when invasive plant species may become a problem.

I.2.6 SALT BUILDUP IN SOILS (BRACKISH AND SALTMARSH)

Salt buildup in soils can limit vegetation establishment above the MHW (mean high water) and MHHW (mean higher high water) elevations of tidal saltwater wetland replacements in areas where the water salinity exceeds 10 ppt. The salt stress elevation ranges are those covered by the spring tide ranges where soil salt concentrations can readily exceed tolerance levels (50 to 60 ppt) of even the most salt-tolerant wetland plant species (Garbisch 1986, Zedler 1984). Substrates throughout these elevations become subject to a buildup of high soil salt concentrations because they are not regularly (daily or twice daily) flooded by saltwater, as are those substrates that lie below MHW and MHHW. Consequently, the soil salt concentrations do not remain close to those of the flooding waters.

The irregular flooding causes increases in salt concentration due to water evaporation during nonflooding periods. Then saltwater is again introduced to the soils during periods of flooding, but generally its duration is insufficient to lower the salt concentrations to those of the flooding waters. When the nonflooding period recurs, the buildup of salt concentration continues.

Even with highly permeable sandy soils, rain and time may not solve the problem. There are saltmarsh replacement sites where certain areas of the sandy soils originally would not support vegetation because of high salt concentrations. Decades later these identical areas continue to remain barren (Garbisch personal communication).

Evidence of a salt contamination problem is the appearance of white salt crystal deposits on the sediment surface when sediments have not been flooded for several days by tide or rain. Analyses of soil samples taken three to four inches below the surface may reflect the problem; however, salinities of these samples may be temporarily reduced by recent precipitation or saltwater flooding and lead to erroneous conclusions. Test planting is a reliable way to verify the problem. Signs of salt stress (leaf wilting and browning at the leaf tips) are often evident from one to five days after planting.

SALT CONTAMINATION TESTING

Test planting is the most reliable method of verifying a soil salt contamination problem.

Corrective solutions:

Not many are practical.

- If frequent watering or irrigation is feasible, the affected areas should be replanted, and watering should begin at frequencies sufficient to eliminate any signs of plant stress and continued until the onset of vigorous plant growth.

- If watering is not feasible, the affected areas should be replanted during the wet period of the growing season when the chance of frequent precipitation is greatest. If the plant species can survive deep planting, then replanting at depths of 7 to 12 inches below the sediment surface where the soil salinities are likely to be the lowest may prove a successful alternative. Never fertilize the plants when planting in salt contaminated sediments, as this will lead to an increase in soil salt concentrations. Fertilization can always be done later, after the plants have rooted and become established. All replanting must use plant materials that have been salt conditioned (see below).

Avoidance solution:

- Specify and ensure, through good construction management, close coordination of the construction of the salt-stress elevation ranges (refer to first paragraph) with the installation of vegetation. If at all possible, specify that tidal saltwater be excluded from this salt-stress zone until it has been prepared and planted. Installing the vegetation into freshly prepared sediments that have not been contaminated by salt generally will overcome the problem. Once the transplants become re-rooted into the sediments (within one month during the growing season), new roots will seek soil depths where salinities are more tolerable.

Plant materials used in the replanting (corrective solution) or planting in the avoidance solution should be specified to be conditioned for at least 15 days to within 10 ppt of the water salinity at the replacement site.

I.2.7 INCORRECT FERTILIZATION PROGRAM

Lack of fertilization may lead to poor plant development and establishment. As a result, plants may fail to overwinter, particularly when the nutrient levels are low in the waters interacting with the replacement site. Normally, a one-time fertilization should be specified when planting and seeding wetland replacement sites (Appendices G.6 and G.7).

If there is an over supply of nutrients at the site, the vegetation often will have excessive top growth, which leads to its slumping and smothering of new growth.

NUTRIENT LOADING & FERTILIZING

Fertilizing is not recommended if the nutrient loads in the water are high in nitrate, ammonium, or ammonia.

Corrective solution:

- If areas of the site appear to be nutrient deficient (i.e., growth below expectancy levels and chlorosis), schedule refertilization during project maintenance and/or monitoring. If, on the other hand, the vegetation appears to have an over supply of nutrients (i.e., excessive productivity is apparent), then cutting of the vegetation should be scheduled before it slumps and smothers new growth.

Avoidance solution:

- Always specify fertilization at the time of planting, unless it is known that the water at the site is high in nitrogen-based nutrients. In this event, do not specify fertilization. Instead, evaluate the need for fertilizing or cutting of the vegetation, as in the corrective solution, during the planned maintenance and/or monitoring.

I.2.8 INSUFFICIENT SITE HYDROLOGY TO SUPPORT THE REPLACEMENT WETLAND

Too many wetland replacement projects have been constructed without adequate prior investigations to verify that the hydrology will be correct for the desired wetland type.

Examples of erroneous assumptions that are often made are given below. These assumptions have led to unsuccessful wetland replacement projects.

EXAMPLES OF ERRONEOUS HYDROLOGY ASSUMPTIONS OFTEN MADE

EXAMPLE A: If there is water in a borrow pit, then the pit can be enlarged to meet the wetland replacement requirements, and the water will be sufficient to sustain the replacement wetland.

EXAMPLE B: An existing wetland can be enlarged to any size as a wetland replacement, and the existing hydrology will be adequate to sustain the enlarged wetland.

EXAMPLE C: If the water in a small sediment basin persists at groundwater elevation, then this basin can be enlarged to any size, and the groundwater will be adequate to sustain the resulting wetland.

EXAMPLE D: If a hole is simply dug to groundwater level at any time of year, a wetland can be developed and sustained at that elevation.

The hydrology for groundwater-driven wetlands is the least verifiable of any other wetland type. The science and technology associated with understanding and reliably predicting the water budgets for groundwater-driven wetland replacement projects is so inadequate that the Research Team cannot recommend them for construction (Appendix E). Other hydrology sources must be demonstrated to be sufficient to support the wetland under design; groundwater contributions should only be considered an unnecessary "extra."

GROUNDWATER HYDROLOGY

Do not design wetland replacements that are supplied by ground water only.

Corrective solution:

NONE, if the designed site hydrology is insufficient to support the replacement wetland.

Avoidance solutions:

- Do not develop groundwater-driven wetland replacements. Conduct adequate investigations prior to the development of the construction plans and specifications to verify that the other hydrology will be correct for the desired wetland type.
- If groundwater-driven wetland replacements are pursued, specify that after the earthwork is completed, the site should be left unvegetated until the groundwater supply is assessed, and the water control structure is adjusted to maintain a constant pool level. Only then should the landscaping design and contract be pursued (Chapter 5.4).

I.2.9 SHADING

Shading can lead to loss of biological productivity, alteration of the normal morphology, massive reduction of densities, and even mortality of many plant species. Certain plant species tolerate partial and even full shade (Table G-8 in Appendix G.1). Generally, they are broad-leaved herbaceous plants, but they include many trees and shrubs as well. The narrow-leaved grasses, sedges, and rushes are often shade intolerant and require substantial amounts of full sun daily.

Although the daily amount of full sunlight required by shade-intolerant plant species has not been reported in the literature, this useful rule of thumb has been found in greenhouse shading experiments: those plants that are intolerant of shade require at least six hours of direct, full sunlight each day during the growing season to maintain normal productivity, rate of spread, and morphology.

> **SUNLIGHT REQUIREMENTS**
>
> Provide shade-intolerant plants with at least six hours/day of direct sunlight.

Corrective solution:

- Symptoms of shading problems include unusual plant morphology (usually abnormal elongations of the plants), poor foliage pigmentation, or unexpectedly low plant densities because of lack of vegetative spread. To correct the problems, open up the affected area to at least six hours of direct sunlight daily during the growing season by removing or pruning shading trees and shrubs.

  Pruning is only a temporary corrective solution, since excessive shading will recur in several years as the trees and shrubs continue to grow.

Avoidance solution:

- Ensure in the construction plans and specifications that those plant species that are shade-intolerant (Table G-8 in Appendix G.1) be provided a minimum of six hours of direct sunlight daily during the growing season.

> **PLANTING ELEVATIONS**
>
> - Planting at the wrong elevations is a very common problem. The designer, rather than the landscape contractor, is usually responsible for correctly establishing at what elevations the material should be planted.
>
> - Use biological benchmarks to confirm the correct elevations for replanting.

I.2.10 PLANTING AT THE WRONG ELEVATIONS

A common mistake in wetland replacement projects is installing plants at the wrong elevations, which results in plant mortality. Incorrect elevations usually result from incorrect design. This is a potential problem for any wetland replacement (tidal or nontidal) where vegetation community zonation—including unvegetated and open water zones—are specified. Unfortunately, the landscape contractor will have to replant under the contract guarantee, even though the problem occurred during design.

Corrective solution:

- Replant at the correct elevations. When the problem does occur, the preparer of the plans and specifications should be contacted, since this problem usually occurs because the designers incorrectly specified the plants at the wrong elevations, i.e., the problem was not caused by the landscape contractor.

If there are biological benchmarks near the wetland replacement site for the various vegetation communities, including open water and unvegetated—and if these benchmarks and the replacement wetland are using the same hydrology—then, setting the correct elevations for replanting should be straightforward.

Avoidance solution:

- Answer the following questions and make certain that the construction plans and specifications reflect the answers and provide specific directives for the planting:
    - Are there precise elevations where the vegetation community zones change and one community will not establish?
    - Are there transitions between the zones (leeway) where several communities will persist?
    - Is there a specific vegetation boundary elevation below which no emergent plants will persist?
    - Is there a person designated to be responsible for marking/staking the various planting zones at the replacement site?

These are important questions whose answers may differ with wetland communities and types.

Assuming that the vegetation community zones are correctly placed as described on the construction plans and specifications, responsible persons must be designated to stake or mark the zones and inspect and approve the staking/marking prior to planting (see last question above).

I.2.11 PLANTING THE WRONG SPECIES FOR THE SITE HYDROREGIME

This problem is similar to the case in the preceding section, where the correct species is planted at the wrong elevation(s). Here, the wrong species is planted at the correct elevation/hydroregime.

This common mistake arises from incorrect design. However, as noted in Section 1.2.10, the landscape contractor may be required to replant under the contract guarantee.

> **SPECIFY THE CORRECT SPECIES FOR THE SITE**
>
> The replacement wetland designer usually is responsible for correctly specifying vegetative species that will match the hydro-regime at the site.

Corrective solution:

- Identify suitable plant species for the site elevation(s) and replant using those species and the proper types of plant materials for the situation.

Avoidance solution:

- Double check all plant species assigned to the various site hydroregimes (site elevations relative to the site water levels) to assure that the assignments are correct. (See tables in Appendix G.1.)

As stated previously, assuming that the species assignments are correctly placed on the construction plans and specifications, persons must be assigned to stake or flag the elevations to be planted and to inspect and approve the staking/flagging prior to planting.

I.2.12 SEEDING RESULTS ARE UNSUCCESSFUL

As discussed in Appendix G.7, reliable seeding techniques and commercial seed sources are available for only a very few wetland plant species. Seeding should not be specified unless reliable seeding techniques are known for the species of interest and unless there is a reliable source of viable seed (pure live seed) available. Otherwise, seeding is likely to be unsuccessful.

Corrective solutions:

- If reliable and successful seeding of the species has not been described or reported, plant the area with nursery plant materials of the species.
- If successful seeding of the species has been described and it is certain that pure live seed was used, then the seeding conditions should be analyzed to try to understand what went wrong. If the reasons for failure can be determined and corrective measures can be taken, then consideration should be given to re-seed the following year. Otherwise, the corrective solution should be to plant the area with nursery plant materials of the species.

SEEDING WETLANDS

- Seeding should be specified only if a successful technique is known and pure live seed is known to be available.
- If seeding is unsuccessful after one attempt, it generally will be less expensive to re-seed several times than to plant.

Avoidance solution:

- Do not specify seeding unless reliable seeding techniques are known for the species of interest and unless there is a reliable source of viable seed (pure live seed) for this species.

I.2.13 UNSUCCESSFUL PLANTING OF THE CORRECT PLANT SPECIES AT THE CORRECT ELEVATIONS (HYDROREGIME)

This problem occurs frequently. It may be related to the problem discussed in Section I.2.6, i.e., salt buildup in soils for saltmarsh or brackish marsh replacement projects. If not, the landscape contractor may have used the wrong planting techniques or unsuitable plant materials for the time of planting. For example:

- Leafed-out unrooted cuttings or bare root trees and shrubs were planted, and the plants died.
- Bare-root herbaceous plants were planted too late in the growing season, resulting in many plant deaths.
- The quality of the plant materials was poor (i.e., improperly handled, under shipment for too long a period, cut too small to have sufficient amounts of stored energy).

- The plant materials were not properly acclimated to the correct water salinity or to hydric soils, or they were diseased.
- The plants were burned by a fast-release fertilizer.
- The plants floated out of the planting holes and died.
- The plants were eaten by wildlife.

Many other possible explanations probably exist. The site conditions before and after planting as well as the history of the plant materials need to be reviewed and tracked by the project sponsor's inspector, contract manager, and landscape contractor to understand the reason for the problem. Otherwise, a solution will not be obvious and replanting could fail again.

Corrective solution:

- Replant after analyzing, understanding, and correcting the reason(s) for the problem.

Avoidance solution:

- Learn from the mistake and avoid its recurrence in future construction plans and specifications.

I.2.14 IMPROPER SEDIMENTS/SUBSTRATES

Sediments at the final grade of the replacement site may be inadequate to support wetland plants and/or the wetland hydrology. The information gathered for the replacement site may have been inadequate, or data may have been overlooked. Thorough site selection studies should prevent this problem, since wetlands can be replaced successfully on a wide range of soils and soil conditions (Appendix F).

Soil compaction problems may be readily corrected through deconsolidation and avoided by including a deconsolidation specification in the plans and specifications.

VALIDATING SEDIMENTS/SUBSTRATES

Validation that the sediments are suitable for the wetland replacement normally is done in Step 2 (Site Selection) of the WRP.

However, the soils/sediments may also be:

- Too sandy—water at the site is lost due to rapid infiltration
- Bedrock or pure clay
- Too pebbly, and wave energies at the site may be sufficient to hold them in suspension, causing plant leaves to be worn down

Corrective solution:

- The site must be re-designed, using the new soil information and construction modified to rectify the problem.

Avoidance solution:

- Conduct adequate site selection investigations.

I.2.15 POORLY DRAINED AND ANOXIC SEDIMENTS

Little is known about why aquatic plant species vary in their tolerance to differing hydroperiods and water depths. Nonetheless, these parameters often dictate where aquatic plant species are and are not found within wetland plant communities.

Even when the proper hydroperiod and/or depth of water is provided in wetland replacement projects, certain plant species will flourish during the growing season but will not overwinter (Garbisch 1989). This suggests that using biological benchmarks to set elevations and elevation ranges for plant species and plant communities may not always lead to successful results. The problem is one of oxygen requirements in dormant wetland plants (McIninch and Garbisch 1991).

> **PLANT SURVIVAL**
>
> Even though the hydroregime is correct, some plants may not survive.

Wetland plant species survive anoxic root environments through various adaptive and avoidance mechanisms. The most significant appears to be an avoidance mechanism in which the plant develops an oxygen-transport path during the growing season from aboveground to belowground plant parts. This produces an oxidized rhizosphere which allows aerobic root/rhizome respiration as well as oxidation of sulfide toxins and supplies oxygen to mycorrhizal symbionts (Mendelssohn and Burdick 1988).

However, during the dormant season, when this oxygen–transport mechanism is no longer functioning, what are the oxygen requirements of the perennial parts of aquatic plant species? McIninch and Garbisch (1991) have found that during the dormant season certain species are:

- Insensitive to an almost complete lack of oxygen, while being frozen in a block of ice for 31 days. These species include:

  - Arrow arum (*Peltandra virginica*)
  - Duck potato (*Sagittaria latifolia*)
  - Lizard's tail (*Saururus cernuus*)

  These species are known to persist in more wetland types and under greater temperature ranges than the other species tested (see below).

- Sensitive to an almost complete lack of oxygen, but not sensitive to being frozen in a block of ice for 31 days. These species include:

  - Common threesquare (*Scirpus pungens*)
  - Cattail rhizomes with stems attached (*Typha latifolia*)
  - Cordgrass (*Spartina alterniflora*)

- Sensitive to both an almost complete lack of oxygen and being frozen in a block of ice for 31 days. These species include:

- Cattail rhizomes (*Typha latifolia*)
- Pickerelweed (*Pontederia cordata*)
- Soft-stemmed bulrush (*Scirpus validus*)

Subsequent studies (McIninch and Garbisch, personal communication) have confirmed that of the five plant species cited above that are sensitive to a lack of oxygen during the dormant season, cordgrass (*Spartina alterniflora*) has the highest sensitivity. It will most certainly die if kept in totally saturated soils during the dormant season.

These results explain why cordgrass will not grow below Mean Low Water in saltmarshes and brackish marshes and why cordgrass and common threesquare (*Scirpus pungens*) will not regenerate after overwintering in highly saturated, poorly drained anaerobic soils or in similar soils resulting from animal "eatouts" (Lunch et al. 1947; Garbisch, personal communication).

The two most problematic species in poorly drained anaerobic soils are cordgrass and common threesquare, with the former being more critical.

Should one or both of these species not overwinter on a tidal wetland replacement site where water is impounded or the soils poorly drain, project sponsors might consider the options below:

OXYGEN IN DORMANT PERIODS

Cordgrass does not grow below MLW or in poorly drained soils because it requires oxygen during the dormant season.

Corrective solution:

- Replant the site, following the construction of ditches to remove the water impoundment or to improve the drainage of the soils. If unsuccessful, consider planting another species, one less sensitive to oxygen deficiencies during the dormant season (see above) and that otherwise should tolerate site conditions.

Should *Scirpus pungens* not overwinter at a nontidal wetland replacement site, project sponsors may elect the option below:

Corrective solution:

- Replant at or just above the pool level at the site. If inappropriate, then consider planting another species less sensitive to oxygen deficiencies during the dormant season (see above) and otherwise adaptable to the site conditions.

Avoidance solution:

- Ensure that whenever *Spartina alterniflora* or *Scirpus pungens* is being specified for wetland replacement projects that the following be clearly stated: tidal sites should be well drained at low tide, with absolutely no impounded water; and for nontidal sites, do not specify *Scirpus pungens* in areas where the depth of water during the dormant season will exceed six inches.

I.2.16 UNSTABLE PEAT BANK DEVELOPMENT

Many rhizome-propagating emergent wetland plant species form a tightly woven root mat that in time emerges above the mineral wetland sediments as a peat bank. They include *Juncus, Phragmites, Scirpus, Spartina, and Typha* species. The productivity of their belowground portions generally is equal to or greater than the aboveground portions (de la Cruz and Hackney 1977, Gallager and Plumley 1979, Good et al. 1982, Hackney and de la Cruz 1986, Roman and Daiber 1984, Stroud 1976, Valiela et al. 1976). *Spartina cynosuroides*, for example, has annual aboveground and belowground productivities as high as 28 tons per acre (Hackney and de la Cruz 1986).

In wetland replacement projects, this belowground biomass generally is not forced into the mineral sediments of the wetland replacement site, but it is directed above these sediments where there is the least resistance to root/rhizome spread. Depending upon the degree of sediment consolidation in the wetland replacement site, the density of vegetation, and the extent of sediment transport to the replacement site, peat banks may emerge quickly from the surface of the mineral sediments at the replacement site in as few as three growing seasons. In one 20 year–old wetland restoration site, the developed peat bank is 12"–18" high (Garbisch personal communication).

> **PEAT BANK EROSION**
>
> Peat banks may rise above the sediment surface in as short a time as three years and be vulnerable to erosion.

A wetland replacement site may be physically stable at the beginning of the project, but it may change dramatically once a vertical peat bank emerges from the sediment surface. Acres of marsh have been known to be undercut and washed away as soon as a peat bank emerged (Garbisch personal communication).

Once a peat bank emerges and is found to be unstable to the interacting wave climate, the solution below may be an option:

Corrective solution:

- Start the development of stone (riprap) edging along the emerged peat bank. Its height must be increased periodically as the peat bank grows. Alternatively, construct a small riprap breakwater two feet in height and otherwise designed for stability under the prevailing conditions. This breakwater would be expected to protect the growing peat bank for 30 to 50 years or until the peat bank exceeded its height.

Avoidance solution:

- Ensure that the wetland replacement site selection and design (plans and specification) processes (Steps and Chapters 2 and 5 in the WRP) consider the development of a vertical peat bank and ensure that the site conditions will be stable as the peat bank develops.

I.3 UNAVOIDABLE PROBLEMS AND THEIR SOLUTIONS

I.3.1 UNUSUAL METEOROLOGICAL CONDITIONS

Unseasonable or unanticipated wet periods are generally not expected to impact wetland replacement projects adversely. The plant species that are associated with wetlands that are occasionally flooded during normally dry periods are expected to survive such events, provided they do not occur often over several successive years.

Severe storms such as hurricanes, cyclones, and tornadoes may inflict severe wind damage to wetland replacement sites. However, the extended hydroperiods and increased depths of water that are associated with such infrequent storms generally will not adversely impact the vegetation.

WATER CONTROL & CONVEYANCE

Normally, excess water conveyed to the replacement site returns to the waterway by means of water control and water conveyance structures..

Corrective solution *(for wind/water damage to plants):*

- Replace the plants

Avoidance solution *(for wind/water damage to plants):*

NONE

Such severe storms may also lead to site erosion problems.

Corrective solutions *(for erosional problems):*

- Physically restore the site
- Construct appropriate erosion control measures so that the problem does not recur
- Replant, as necessary

Avoidance solution:

- Anticipate occasional storms; include the necessary erosion control measures in the construction plans and specifications so that the problem does not arise.

Wetlands throughout the nation that are seasonally and temporarily flooded typically will undergo dry periods that usually occur during the growing season. Problems that typically arise in these wetland types because of droughty conditions generally would be considered avoidable. They can be anticipated and dealt with in the project plans and specifications by specifying drought-tolerant plants and a normal watering program.

If these droughty periods are particularly long-lasting, they may jeopardize the wetland replacement project unless the construction plans and specifications include automatic irrigation and other emergency watering.

Corrective solution:

- Initiate an intensive watering program. This could be a very expensive exercise unless the drought is short lived.

Avoidance solution:

- Anticipate the problem by specifying intensive irrigation/watering in the construction plans and specifications so that funds will be available, if needed.

Even wetlands that are more permanently flooded and tidal wetlands may be severely damaged by extended droughts. Perennial streams may dry up due to the lack of groundwater discharge. River and lake levels may drop drastically. Saltwater may intrude into tidal freshwater areas.

Such unusual occurrences are considered unavoidable, and there may not be any corrective solution. The plant species in these wetland types normally are not drought resistant. Saltwater cannot be pushed back to the sea. Watering of the site may not work if the volume requirements are too great or if the soils are of a type that loses water rapidly from infiltration. There may be instances where watering is a corrective solution; however, project funds may not allow for it, if the emergency was not anticipated. For these reasons, there probably are no practical avoidance solutions for such unusual occurrences. Planning for emergency watering probably should not be a part of the construction plans and specifications because of the very low probability of a need.

I.3.2 DAMAGE FROM ICE

If water freezes when covering a nontidal or tidal wetland site, the persistent emergent herbaceous and woody plants will become locked in the ice. If it rains or if the tide rises before the ice thaws, the ice will float upward, and the plants may be uprooted.

Corrective solutions:

- Replant the herbaceous uprooted plants before they die. Cut down their aboveground plant parts to one or two inches above the ground surface after (or before) planting, so that ice cannot lift out the plants again.

- If the uprooted plants are woody, dead, or cannot be found for resetting, replant early in the next growing season to maximize rooting of the plants in the sediments and to minimize the chance of uprooting again.

Avoidance solution:

- Specify that all woody plant materials are to be planted at the beginning of the growing season so that they are well-rooted prior to winter. Persistent herbaceous emergent plants also can be planted early in the growing season or following its end. In the latter case, specify that the aboveground plant parts be clipped to about one or two inches above the ground level before or following planting.

Even when planting trees and shrubs early in the growing season, uprooting by floating/drifting ice may be unavoidable. It has been suggested (Garbisch 1989) that planting trees and shrubs early in the growing season without fertilizing or by fertilizing with a low nitrogen and high phosphorous formulation to promote root development may be an avoidance solution. However, this idea has not been tested.

If the wetland replacement is in an exposed area, wind- or current-driven ice could cause smashing and cutting of woody vegetation. The corrective solution would be to replant and hope that conditions do not recur. There is no avoidance solution.

ANCHORING PLANTS

Anchoring plants may prevent them from being uprooted (Chapter 5).

I.3.3 LITTER AND DEBRIS DEPOSITS

Litter and debris deposits can present significant problems for wetland replacement projects. Occasionally the problem can be minimized in the design phase (construction plans and specifications) of the WRP; however, often the problem is unavoidable.

The problem is most apparent for tidal and nontidal (regularly to permanently flooded) wetlands dominated by herbaceous vegetation and for all wetlands in urban settings.

Organic litter from the standing crops of the replacement wetland and possibly from surrounding wetlands is a problem most apparent throughout the sides of the wetlands facing the prevailing winds during the dormant season. Natural processes during this season harvest the aboveground standing crops of the semi-persistent and persistent emergent vegetation. The floating litter then is driven in wracks along the wetland shores facing the prevailing winds. These wracks smother existing shoreline vegetation as it tries to emerge during the beginning of the next growing season. Because the wracks normally are lifted or floated during high water levels to elevations above the normal pool level or normal high tide for the wetlands, the relatively dry organic matter decomposes slowly and is subject to repeated movements to higher elevations during storm events, repeatedly harming existing vegetation during the subsequent growing season.

Corrective solution:

- Remove the wracks of litter during scheduled maintenance and dispose of them off site. If wracks have already killed vegetation, replanting will be necessary.

WRACK ACCUMULATION

Wrack accumulation is a natural process, occurring in all wetlands. A host of insects and invertebrates live within the organic wrack. An alternate avoidance solution is not to vegetate areas where debris is expected to accumulate.

***Avoidance solutions** (in part):*

- Exclude floating organic litter that arises from surrounding wetlands by connecting the replacement wetland to surrounding wetlands by means of submerged culvert(s).
- Provide channels throughout the litter deposition zone(s) to collect the litter, facilitate its decomposition, and export it and its decomposition products from the replacement wetland.

- Place stone armor throughout the likely litter deposition zone(s), and allow the litter to collect there (Garbisch 1986).
- Do not vegetate areas where debris is expected to accumulate. The wrack deposits will form a habitat for insects and invertebrates.

In addition to the problem of wrack, during the growing season winds can blow floating mats of algae onto emergent vegetation throughout the wetland and its shores, injuring or destroying the vegetation.

Corrective solutions:

- Remove the algae during scheduled maintenance and dispose of it off site.
- Use algaecides to control the algae. Some algaecides may be used in nontidal wetlands when there is limited water flowing through the wetland. Such algaecides are not toxic to fish, wildlife, or emergent wetland species.

Avoidance solution:

NONE

Wetland replacements in urban areas that are connected to water bodies to which storm sewers discharge may receive bottles, cans, plastic products, and other debris following every storm event. In some instances the volume of debris may be so great that its collection and disposal is not practical.

Corrective solution:

NONE

Avoidance solution:

- Do not select wetland replacement sites that will intercept discharged water from storm sewers.

I.3.4 PLANT DISEASE

Wetland plants are not immune to disease, but there are no reports in the literature that disease is a serious problem. However, there is one plant species for which disease may be a serious threat: *Spartina alterniflora*, cordgrass, which is associated with salt and brackish tidal marshes throughout the East and Gulf coasts of the United States. In the nursery and in natural wetlands, *S. alterniflora* is a grass that appears to be highly susceptible to infestation by rust (Garbisch, personal communication).

Because *S. alterniflora* generally grows in monotypic stands in salt and brackish marshes, spread of the rust to the nearest neighbors is fast and efficient. A 3.4-acre wetland replacement in Delaware

RUST INFESTATIONS

- For cordgrass, rust can be a problem in natural and replaced wetlands and in the nursery.
- Rust can have the greatest harm on Cordgrass when it infects early in the growing season.

which was uniformly vegetated and doing well for six years became infested by rust early in its seventh year. It its eighth year, *S. Alterniflora* covered less than 0.1% of the wetland (Garbisch, personal communication).

Rust can infect *S. alterniflora* at any time during the growing season, but its damage is greatest when infestation occurs at the beginning. In this instance, the entire plant can be killed before it can reproduce (i.e., produce new shoots from rhizomes). At the end of the growing season, rust may accelerate the death of the aboveground standing crop. However, the new dormant shoots are cleaned of rust spores by tidal washing and the impact of the infestation is negligible.

Upon dying, the bright orange rust turns black, leaving long black streaks covering the leaves and stems of the plants. This evidence will persist as long as the stems and leaves stay intact—even for several years, as the litter is washed and deposited at relatively high and dry elevations.

Avoidance solution:

NONE

Corrective solution:

This solution only applies if the infestation is beginning, i.e., if you can see the rust upon close examination of the plants in the wetland. If the entire wetland looks orange from a distance, there is no corrective solution.

- At ebb tide as the water recedes from the site, apply a contact or systemic fungicide that is labeled for rust. Effective trade-name fungicides include BAYLETON, BENLATE, and STRIKE.

I.3.5 VANDALISM

Vandalism is most likely to take place in urban wetland replacements where it may consist of anything imaginable: pulling plants out, cutting trees and shrubs, dumping garbage and trash, spraying with herbicides, running over planted areas with ATVs, channelizing tidal saltwater into a nontidal freshwater wetland replacement.

Corrective solution:

- Replant. However, this would be unproductive unless the vandalism is controlled. Consequently, in addition to replanting, it may be necessary to construct a fence around the entire site or construct barriers against ATV passage. Fencing the site is an expensive solution that may restrict wildlife use of the site, which might be a function of the replacement.

Avoidance solution:

- Anticipate the vandalism and specify protection in the plans and specifications.

In one instance a project sponsor convened a public meeting with the residents surrounding the site and explained the objectives of the project. As a result, they participated in replanting and protecting the site.

I.3.6 ANIMAL MANAGEMENT AND CONTROL

A problem that appears to be common to all wetland types throughout the United States is animals grazing on, and excavation of, aboveground and belowground parts of woody and herbaceous plants by livestock, fish, swan, geese, ducks, crabs, deer, feral goats, feral pigs, muskrats, nutria, beavers, rabbits, and small rodents. All have caused major problems in establishing vegetation at wetland replacement sites (Garbisch 1989).

> **DAMAGE FROM GRAZING**
>
> Wildlife herbivory is, by far, the most common problem for wetland replacements.

In urban areas, where prime wildlife habitats may be rare, replacements may provide such attractive habitats that resident and transient wildlife populations rapidly consume what they can of wetland produce before it can rejuvenate. This imbalance leads to the rapid demise of the replacement wetland.

For example, many herbaceous wetland species form tightly woven root mats that rapidly develop into peat banks (Section I.2.16). Animal "eatouts" (primarily by muskrats and geese) of underground plant biomass in the peat marshes lead to the destruction of the physical structure of the peat and to the development of a loose muck (ooze) with decaying plant discards. The soils also change chemically from organic decomposition and increased bacterial activity. (Destruction of the peat structure ranges from eight inches deep for geese to 20 inches for muskrats.) (Lunch et al. 1947).

Destroyed marshes may remain unproductive for decades, and it may take many years for the original vegetation to re–establish. In salt and brackish tidal marshes, annual plants (e.g., *Pluchea purpurascens*) and the perennial Dwarf Spikerush (*Eleocharis parvula*) rapidly inhabit the oozy sediments following "eatouts" (Lunch et al. 1947; Garbisch, personal communication). The reason for the slow recovery to the original vegetation is that many of the rhizome propagating species that produce peat banks cannot overwinter in sediments lacking oxygen (Section I.2.15).

Whether there are any avoidance or corrective solutions depends upon the objectives of the wetland replacement, the specific wildlife that are involved, the size of the project, and possibly politics and policy, as exemplified below:

> **AN EXAMPLE OF THE LACK OF A CORRECTIVE SOLUTION TO A WILDLIFE PROBLEM**
>
> At an urban wetland replacement site where a population of exotic geese were repeatedly denuding the site, none of the wildlife agencies, wetland regulatory agencies, or mayor of a major city in the northeast would assist with, or provide permits for, the removal of the geese from the area.

A discussion follows below about various wildlife problems and possible corrective and avoidance solutions.

Should the wildlife populations exceed the numbers which the wetland can support, management to reduce the population is the only corrective solution. Effective management may require year-round removal or hunting. These solutions require special permits from state and federal fish and wildlife departments, wetland regulatory agency approval, and possibly special approvals from the town, city, or county where the project is located.

If the project is sizable and the problem populations are fish and avifauna, corrective and avoidance solutions will be limited. Fencing the entire replacement wetland might be a possible solution, but it may also conflict with the replacement objectives or cost too much.

If the wetland replacement type is a tidal or nontidal marsh, wildlife problems often occur within the first year or two or until uniform vegetation cover is achieved.

Consequently, plant spacing is an important consideration as an avoidance solution when animal problems are expected. The closer the spacing, the more rapidly uniform groundcover appears. For rapidly spreading herbaceous plants, two feet on center generally is sufficient to provide uniform groundcover within one growing season. If the soils are compacted, or if the plants are non–spreading bunch species, tighter spacing should be used. Seeding, when feasible, will lead to the greatest density groundcover in the shortest period of time (Appendix Sections G.6 and G.7).

The timing of planting may be important as a corrective or avoidance solution when animal problems are seasonal. Many animals will be most destructive during the winter months when food sources are scarce. Migratory animals may present problems during their migration periods. In general, planting should be scheduled to provide the most mature vegetation and the most dense cover by the time animal problems are expected.

WILDLIFE DAMAGE ISSUES

- Wildlife does the greatest damage when marshes are young, not uniformly vegetated, and root mats are not well developed.
- The timing of planting may be important to minimize animal depredation.

In forested wetland replacements, plants that are three to four feet tall will avoid problems from rabbits and small rodents. However, they will not avoid damage from deer, beaver, and muskrat.

Although deer have vegetation preferences that vary geographically, they will eat almost any plant, shrub, or young tree. (David Marquis, personal communication). Thus, the Research Team does not recommend avoiding deer problems by specifying non-preferred plant species. A number of mechanical devices and chemical treatments have been tested, and some are discussed briefly below.

A translucent plastic tree shelter, TUBEX, protects woody plant species from herbivory and increases transplant survivals and early growth rates. Its wide acceptance in Britain has stirred active interest in it throughout the United States. TUBEX is available in various heights up to six feet. It is to be installed one inch below the ground surface to maintain the proper air environment within the shelter and to minimize small rodent disturbance at the base of the plant. The effectiveness of TUBEX in forested wetland replacement projects has yet to be tested.

One foreseeable problem with TUBEX in wetland replacement projects is the soil erosion induced at the base of the shelter and the resulting loss of structural integrity of the shelter that may occur as surface water flows by. However, TUBEX may have great potential

MINIMIZING DAMAGE BY DEER

Other types of tree guards, as well as various types of fencing, have been used successfully to avoid browsing by deer.

as an avoidance solution to animal problems in forested wetland sites where the velocity of such water flow is expected to be negligible.

Several animal repellents are broadly used in upland habitats and appear to have potential for use in wetland replacement projects as avoidance solutions to animal problems.

Methiocarb is a chemical (3–5–dimethyl–4–[methylthio]phenol methylcarbamate) that has been found to show great promise on grasses in alleviating Canada geese foraging (Conover 1985). Methiocarb sickens but does not kill the geese. The EPA has approved its use as a bird repellant on blueberries, cherries, and corn seed. Experimental permits would have to be secured for use of it on wetland replacement projects. Methiocarb is marketed by Mobay Chemical Corporation as MESUROL.

RO–PEL is a contact animal repellent that reportedly remains active for extremely long periods, including rainy periods and winter snows. It can be used on seeds as well as dormant and growing plant materials. It is reportedly effective against beavers, cats, coyotes, crows, deer, moose, dogs, elk, foxes, gophers, horses, mice, voles, opossums, porcupines, rabbits, raccoons, rats, skunks, squirrels, wolves, woodpeckers, bears, cattle, and monkeys.

DEER-AWAY is a repellent that has been found to be effective against black-tailed deer (mule deer), white-tailed deer, and Roosevelt elk. One application of it remains effective for at least two months. It is available as a two-part kit for spraying or as a powder for dusting damp/wet branches, leaves, or needles.

Wildlife can also cause hydrology changes at wetland replacement sites; for example, beavers may build dams and alter the intended hydrology.

Corrective solution:

- Remove dams to restore hydrology and trap and relocate the beavers. The difficulties and permits involved with this solution have been discussed above.

Muskrat may also alter hydrology by tunneling through water retention berms.

Avoidance solution:

- Design water retention berms to be at least 30 feet wide at the pond level.

Corrective solution:

- Fill tunnels and implement a muskrat management program. It may be necessary to reconstruct berms, as discussed in the avoidance solution, to prevent muskrat from retunneling.

I.4 REFERENCES CITED

de la Cruz, A.A. and C.T. Hackney. 1977. Energy value, elemental composition and productivity of belowground biomass of a Juncus tidal marsh. Ecology 58:1165–1170.

Gallager, J.L. and F.G. Plumley. 1979. Underground biomass profiles and productivity in Atlantic coastal marshes. American Journal of Botany 66:156–161.

Garbisch, E.W. 1986. Highways and Wetlands: Compensating for Wetland Losses. Report No. FHWA–IP–86–22. U.S. Department of Transportation, Federal Highway Administration. 66 pp.

Garbisch, E.W. 1989. Wetland enhancement, restoration, and construction, pp. 261–175. In S.K. Majumdar, R.P. Brooks, F.J. Brenner and R.W. Timer, Jr. (Eds.), Wetlands Ecology and Conservation: Emphasis in Pennsylvania. The Pennsylvania Academy of Science.

Good, R.E., N.F. Good, and B.F. Frasco. 1982. A review of primary production and decomposition dynamics of the belowground marsh component, pp. 139–157. In V.S. Kennedy (Ed.), Estuarine Comparisons. Academic Press, New York.

McIninch, S.M., and E.W. Garbisch. 1991. Oxygen requirements in dormant wetland plants. Wildflower 4(1):6–12.

Hackney, C.T., and A.A. de la Cruz. 1986. Belowground productivity of roots and rhizomes in a giant cordgrass marsh. Estuaries 9(2):112–116.

Lunch, J.J., T. O'Neil, and D.W. Lay. 1947. Management significance of damage by geese and muskrats to Gulf coast marshes. Journal of Wildlife Management 11(1):50–76.

Roman, C.T. and F.D. Daiber. 1984. Aboveground and belowground primary production of two Delaware Bay tidal marshes. Bulletin of the Torrey Botany Club 111:34–41.

Stroud, L.M. 1976. Net Primary Production of Belowground Material and Carbohydrate Patterns of Two Heights of *Spartina alterniflora* in the North Carolina Marshes. Ph.D. Thesis. North Carolina State University, Raleigh, North Carolina. 140 pp.

Valiela, I., J.M. Teal, and N.Y. Persson. 1976. Production and dynamics of experimentally enriched salt marsh vegetation. Limnology and Oceanography 21:245–252.

Zedler, J.B. 1984. Salt Marsh Restoration: A Guidebook for Southern California. California Sea Grant College Program. Report No. 7-CSGCP-009. La Jolla, California.

APPENDIX J
EVALUATION FOR PLANNED WETLANDS (EPW)

J.1 INTRODUCTION

The Evaluation for Planned Wetlands (EPW) is a rapid-assessment procedure for assessing and designing wetland functions in replacement or planned wetlands (Bartoldus et al. 1994a). The EPW has been developed specifically for use by wetland designers to overcome problems with existing wetland function assessment techniques in designing for functions in the replacement wetland. Specifically, it is the only procedure that highlights wetland components or elements which have been confirmed in the technical literature or actual experience as important to the design of one or more wetland functions. Through use of the EPW, the user (1) documents the procedures and results to help with design and review of the replacement wetland, (2) facilitates wetland design by establishing whether or not a replacement area will achieve defined replacement wetland function goals, and (3) identifies validated threshold values for elements used in function design.

The EPW compares and highlights differences between the wetland assessment area (WAA) and the replacement wetland based on their capacity to provide six functions (see below and Table J-1). The results are documented on forms and data sheets designed to document the procedure. Comparisons may include any of the following:

- **Alternate designs:** Evaluate different design strategies at the same location
- **Conceptual mitigation plans:** Assess conceptual plans for different alternative wetland replacement sites to determine limitations or advantages for providing wetland functions
- **Mitigation goal attainment:** Evaluate if a constructed wetland corresponds to the design and persists through time (one or more years after construction)
- **Initial and future mitigation goals attainment:** Compare the replacement wetland upon establishment to the desired future conditions when mitigation goals (such as forested wetlands) cannot be achieved within the wetland establishment period
- **Replacement wetland to reference wetlands:** Compare the replacement wetland with a reference wetland that has elements to be replicated in the replacement wetland
- **Wetland restoration and enhancement:** Compare restoration of enhancement efforts of previously drained, altered, or existing wetlands.

The EPW is considered distinct from the U.S. Army Corps of Engineers (Corps) new wetland assessment procedure currently under development (Bartoldus 1994b). The Corps is developing generic assessment models for functions in each hydrogeomorphic wetland class. These will later be refined for use with regional hydrogeomorphic wetland functions. On the other hand, the EPW assessment models are comprehensive in order to incorporate elements critical to functional design. Thus, the EPW provides a more focused procedure for evaluating and designing replacement wetlands. Also, because the EPW has been developed as a tool to help in the design of wetland functions, it also incorporates a section of guidelines which provides additional information on functional design not incorporated into the COE models (Bartoldus 1994b).

J.2 THE SIX WETLAND FUNCTIONS THAT THE EPW EVALUATES

The EPW allows evaluators to measure a replacement wetland's potential to provide the following six wetland functions (abbreviations in parenthesis):

- **Shoreline bank erosion control (SB):** Capacity to provide erosion control and to dissipate erosive forces at the shoreline bank
- **Sediment stabilization (SS):** Capacity to stabilize and retain previously deposited sediments
- **Water quality (WQ):** Capacity to retain and process dissolved or particulate materials to the benefit of downstream surface water quality
- **Wildlife (WL):** Degree to which a wetland functions as habitat for wildlife as described by habitat complexity
- **Fish—tidal (FT), non-tidal stream/river (FS), non-tidal pond/lake (FP):** Degree to which a wetland habitat meets the food/cover, reproductive, and water quality requirements of fish
- **Uniqueness/heritage (UH):** Presence of characteristics that distinguish a wetland as unique, rare, or valuable

The EPW uses 7 to 20 elements to evaluate each of the above functions, for a total of 81 elements in Table J-1. An element is a physical, chemical, or biological characteristic of the wetland that, when combined with other elements, establishes a wetland's capacity to perform a function.

J.3 OVERVIEW OF THE EPW PROCEDURE

J.3.1 BASIC STEPS

The EPW is comprised of seven steps:

- **Step 1: Define the scope of the evaluation:** describe evaluation objectives and select functions
- **Step 2: Characterize the wetland assessment area:** identify the project area, delineate the WAA, prepare maps, and complete a cover sheet (Figure J-1)
- **Step 3: Assess the wetland assessment area:** complete data sheets (Figure J-2), calculate Functional Capacity Indices (FCIs), calculate Functional Capacity Units (FCUs) (Figure J-3)
- **Step 4: Set goals for the replacement wetland:** define the goals of the replacement wetland, define the type of comparison, determine the target FCUs, and estimate the minimum area required to meet goals (Figure J-4)
- **Step 5: Select the replacement wetland site:** identify and screen potential sites and select the site
- **Step 6: Design the replacement wetland:** identify the conditions needed to achieve the replacement wetland goals and prepare the design

- **Step 7: Assess the replacement wetland design:** complete the EPW data sheets, calculate the FCIs and FCUs, and determine whether or not the goals are met (Figures J-2, J-3, J-4, and J-5)

J.3.2 THE EPW's UNITS OF COMPARISON

Users of the technique assign a numerical score between 1.0 (highest) to 0.0 (lowest) to each of the 81 elements (and letter codes where information does not apply [NA] or information is not available [INA]). A score of 1.0 for a given element implies that a particular condition is optimal for maximizing a particular wetland function, while a score of 0.0 suggests that condition is unsuitable for maximizing a given wetland function. Users of the technique fill in the numerical values for each element on data sheets.

J.3.3 ELEMENTS, FUNCTIONAL CAPACITY INDICES (FCIs), AND FUNCTIONAL CAPACITY UNITS (FCUs)

The basic comparison begins at the level of the element. Elements contribute separately to a function, with 7-20 elements of the 81 total, characterizing each function. Next, the Functional Capacity Index (FCI) combines the element scores for each function, without consideration of the wetland's size. Finally, the product of a function's FCI and the area of the wetland that performs this function yields the Functional Capacity Unit (FCU). FCUs are not calculated for the last function, Uniqueness/Heritage because it is independent of the wetland's size and is either present (FCI = 1.0) or absent (FCI = 0.0). The EPW does not sum FCIs and FCUs into a total score; rather, they remain separately as the main units of comparison between an impacted wetland's assessment area and its replacement wetland. (Sample calculations are provided in Environmental Concern, Inc.'s full document.)

J.4 EPW ASSUMPTIONS AND LIMITATIONS

Users of the EPW should be aware of the assumptions and limitations described below when using the technique.

J.4.1 ASSUMPTIONS

The full EPW text explains the assumptions of the technique design in detail; the following list summarizes them:

- Six FCIs express a wetland's capacity to perform each of the specific wetland functions.
- The four different classes of wetlands cannot be compared directly, especially for the wetland functions of fish and wildlife.
- Seven to 20 major elements determine the six wetland functional capacities.
- Wetland size relates directly to wetland capacity to perform a function, i.e., FCI x area = FCU.
- The EPW indirectly considers landscape context in its approach.
- The uniqueness/heritage functions of two wetlands cannot be compared.

J.4.2 LIMITATIONS

- The FCIs and FCUs are estimates; they are not direct measures of functional capacity.
- This version of the EPW assesses only six functions

  The following functions were excluded from consideration because of their complexity and, in some cases, the need for extensive field studies:

  - Groundwater recharge and groundwater discharge
  - Floodflow alteration (authors of the EPW are preparing a rapid assessment technique for this function)
  - Stormwater management
- The technique provides an ecosystem–, not a landscape–level, assessment
- Like other rapid assessment techniques, the EPW has a low level of accuracy; more reliable data (detailed field studies) are usually cost and time prohibitive, however.
- The function models describe functional capacity. The technique does not consider opportunities present (e.g., pollutant input)
- The technique's method for calculating the size of a replacement wetland may not be valid for some of the functions.

TABLE J-1
The 81 EPW Elements Used to Evaluate Planned Wetland Functions

ELEMENT (FUNCTION CODES)*	ELEMENT (FUNCTION CODES)	ELEMENT (FUNCTION CODES)	ELEMENT (FUNCTION CODES)
Water contact with toe of bank (SB, WQ)	Plant (basal) cover—tidal (FT)	Vegetation/water interspersion (WL)	Available fish cover/attractors (FT, FS, FP)
Shoreline bank stability (FT, FS, FP)	Rooted vascular aquatic beds in erosion areas (SB)	Steepness of existing shore** (SB)	Islands (WL)
Fetch (SB)	Rooted vascular aquatic beds (lower shore zone) (FT)	Steepness of planned wetland shore (SB)	Obstruction to fish passage (FT, FS, FP)
Shoreline structures/obstacles (SB)	Plant height—upper shore zone (SB)	Wetland slope (SS)	Percent pool areas (FS)
Disturbance at site [SS] (SB, SS, FT, FS, FP)	Plant height—entire wetland (WQ)	Hydrologic condition (WQ)	Current velocity within pools (FS)
Disturbance at site [WQ] (WQ)	Root structure—upper shore zone (SB)	Wetland width (WQ)	Bank undercut (FS)
Disturbance of wildlife habitat (WL)	Root structure—entire wetland (SS)	Wetland site size (WL)	Spawning substrate (FS, FP)
Disturbance in channel/open water (FT, FS, FP)	Vegetation persistence—upper shore zone (SB)	Fish habitat size (FS, FP)	Spawning structures (FS, FP)
Surface runoff (bank erosion) (SB)	Vegetation persistence—entire wetland (SS, WQ)	Detention time (WQ)	Drawdown (FP)
Surface runoff (wetland erosion) (WQ)	Vegetation overhang (FS, FP)	Sheet vs. channel flow (WQ)	Refuge during drought/freeze** (FP)
Boat traffic (SB)	Aboveground plant biomass (FS, FP)	Average water depth (WQ)	Endangered species (UH)
Water level fluctuation (SB, SS, WQ)	Layers (WL)	Gross contamination (WL)	Rarity (UH)
Most permanent hydroperiod (FT)	Condition of layer coverage (WL)	Water quality ratings (FT, FS, FP)	Unique features (UH)
Spatially dominant hydroperiod (FT)	Spatial pattern of shrubs and/or trees (WL)	Nutrients/sediment/contaminants (FT, FS, FP)	Historical or archaeological significance (UH)
Hours of sunlight (SB)	Difference in layers** (WL)	Dissolved oxygen (FT, FS, FP)	Natural landmark (UH)
Substrate suitability for vegetation establishment (SB)	Cover types (WL)	pH range (FS, FP)	Connected to Wild and Scenic River (UH)
Dominant substrate (WQ)	Ratio of cover types (WL)	Maximum water temperature (FT, FS, FP)	Park, sanctuary, etc. (UH)
Substrate suitability for fish (FT)	Cover type interspersion (WL)	Turbidity (FS, FP)	Scientific research site (UH)
Plant (basal) cover—upper shore zone (SB)	Undesirable species (WL)	Shape of upland/wetland edge (WL)	
Plant (basal) cover—entire wetland	Difference in cover types** (WL)	Shape of wetland/water edge (FT, FS, FP)	
Leaf litter and debris cover (SS)	Percent open water (WL)	Wildlife attractors (WL)	

*SB=shoreline bank erosion control, SS=sediment stabilization, WQ=water quality, WL=wildlife, FT=fish-tidal, FS=fish-stream, FP=fish-pond, UH=uniqueness/heritage

**Not used to calculate Functional Capacity Index (FCI)

J.5 REFERENCES CITED

Bartoldus, C. C., E. W. Garbisch, and M. L. Kraus. 1994a. Evaluation for Planned Wetlands (EPW). Environmental Concern, Inc. St. Michaels, Maryland, 310 pp.

Bartoldus, C. C. 1994b. What is the relationship between the EPW and the Corps' new wetland assessment procedure? *Wetland Journal* 6(3):4.

EVALUATION FOR PLANNED WETLANDS (EPW) Cover Sheet		
PROJECT TITLE:		
ASSESSMENT DATE(S): *WAA:*	*planned wetland:*	
INDIVIDUAL(S) PERFORMING EVALUATION AND AFFILIATION:		
LOCATION (e.g., City, County, State, Waterway/Watershed): *WAA:* *planned wetland:*		
ASSESSMENT OBJECTIVES: (note assumed point in time, e.g., peak of first growing season for planned wetland)		
CHECK FUNCTIONS ASSESSED.	*WAA*	*planned wetland*
Shoreline Bank Erosion Control		
Sediment Stabilization		
Water Quality		
Wildlife		
Fish (Tidal)		
Fish (Non-tidal Stream/River)		
Fish (Non-tidal Pond/Lake)		
Uniqueness/Heritage		
DESCRIPTION OF PROJECT AREA: Include information relevant to the assessment (e.g., NWI classification, description of hydrogeomorphic class(es), land use, climate). *WAA:* *planned wetland:*		
CHECK SEASONAL CONTEXT OF THE ASSESSMENT: Average Dry Wet In most situations, the wetland can be readily evaluated by considering average site conditions. However, in some regions (e.g., arid) it may be preferable to evaluate the wetland for different conditions. Please provide explanation if average conditions are not used.		
EXPLANATION OF CHANGES OR MODIFICATIONS TO EPW:		
	Yes	No
Were any changes, deletions, or additions to element conditions and/or assigned scores made? If so, explain below. Cite literature and/or document personal communication(s) with experts.		
Were any changes made to the FCI models? If so, explain.		
Is the planned wetland designed with the goal of removing specific nutrients? If so, explain. Note: modification of the Water Quality FCI model and elements may be required to insure a focus on the removal efficiency for specified nutrients. Refer to Chapter 6 and available literature.		
Explanations:		
PLANNED WETLAND GOALS: Target FCIs and Target FCUs are recorded in Tables A. 1 and A. 2. Other pertinent information may be provided here.		

FIGURE J-1

Example of Cover Sheet
(Source: Bartoldus 1994a)

ELEMENT	SELECTION OF SCORES FOR ELEMENT CONDITIONS	SELECTED SCORES FOR ELEMENTS		DIFFERENCE IN SCORES (Planned-WAA) If both scores are NA, record NA
		WAA	Planned Wetland	
1a. Water contact with toe of bank (see Figure A.1)	[SB, WQ]*			Assume NA = 1.0
a. No shoreline bank.	NA			
b. Infrequent water contact at toe of bank, i.e., no undercutting of bank (e.g., contact once annually or less).	1.0	0.5	1.0	(+)
c. Occasional water contact at toe of bank (e.g., contact once a month).	0.7			
d. Moderate water contact at toe of bank (moderate undercutting of bank).	0.5			
e. Frequent water contact at toe of bank (severe undercutting of bank).	0.1			

FIGURE J-2

Example of Data Sheet: Completed for Planned Wetland (Source: Bartoldus 1994a)

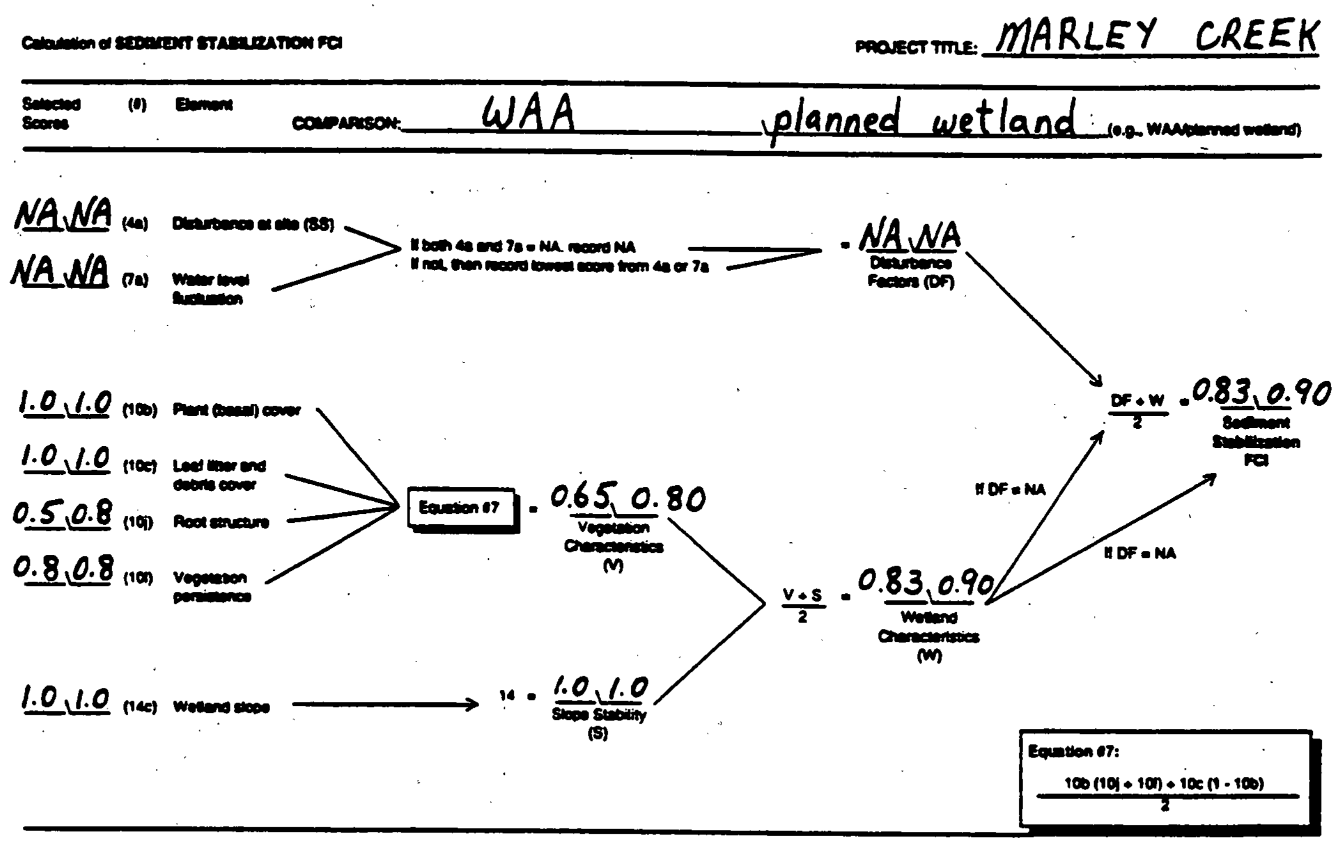

FIGURE J-3

Example of Model Used to Calculate FCIs: Answers completed for WAA and Planned Wetland (Source: Bartoldus 1994a)

Project Title: *Marley Creek*

Comparison between WAA # 1 and planned wetland # 1

Function	WAA			Goals for Planned Wetland**					Planned Wetland			Check if goals met
	FCI	AREA	FCUs*	Target FCI	R	Target FCUs	Predicted FCI	Minimum Area	FCI	AREA	FCUs*	
SB	0.7	0.5 acre	0.4	> 0.7	1	0.4	0.7	0.5 acre	0.97	2 acre	1.9	✓
SS	0.83	1.5 ac	1.2	> 0.8	1	1.2	0.8	1.5 ac	0.90	2 ac	1.8	✓
WQ	0.92	1.5 ac	1.4	> 0.9	1	1.4	0.9	1.6 ac	0.83	2 ac	1.7	NO
WL	0.54	1.5 ac	0.8	> 0.6	1	0.8	0.6	1.3 ac	0.35	2 ac	0.7	NO
FT	0.48	1.5 ac	0.7	> 0.5	1	0.7	0.5	1.4 ac	0.20	2 ac	0.4	NO
FS	X	X	X	X	X	X	X	X	X	X	X	X
FP	X	X	X	X	X	X	X	X	X	X	X	X
UH	1.0			1.0					1.0			✓

*FCUs = FCI x AREA
**Target FCI = *goal* established by decision makers
R = multiplying factor established by decision makers
Target FCUs = $FCU_{WAA} \times R$ (i.e., planned wetland *goal*)
Predicted FCI = FCIs which designers presume planned wetland may achieve at a particular site (Note this may be greater than Target FCI).
Minimum Area = Target FCUs/Predicted FCI

FIGURE J-4

Calculations Completed for Planned Wetland FCUs
(Source: Bartoldus 1994a)

PROJECT TITLE: *Marley Creek*

Function	Functional Capacity Index: WAA	Functional Capacity Index: Planned Wetland	Element Number	Difference	Explanation
Shoreline Bank Erosion Control (SB)	0.7	0.97	1 a	+	Undercutting observed in WAA
		Target: >0.7	10 i	+	Planned wetland has more root mat forming plant species
Sediment Stabilization (SS)	0.83	0.90	10 j	+	Planned wetland has more root mat forming plant species
		Target: >0.8			
Water Quality (WQ)	0.92	0.83	1 a	+	Undercutting in WAA; planned wetland design prevents this
		Target: >0.9	15	-	Less water/wetland contact because planned wetland contains high and low marsh
Wildlife (WL)	0.54	0.35	11 a	-	Fewer layers in planned wetland
			11 b	-	Planned wetland predominantly 1 layer
			11 c	NA-1.0	No shrubs in planned wetland
			12 a	-	Fewer cover types in planned wetland
			12 b	-	Proportion of cover types not balanced
			12 c	-	Less interspersion in planned wetland
		Target: >0.6	12 e	1.0-NA	Planned wetland does not have tall persistent and bushy deciduous cover types
Fish (FT, FS, FP)	0.5	0.2	1 b	+	Planned wetland has no shoreline bank erosion
			7 c	-	Hydroperiod less favorable for fish in planned wetland
			9 c	-	Substrate less suitable for fish in planned wetland
			21 b	+	Wetland/water edge in planned wetland irregular compared to regular edge in WAA
		Target: >0.5	22 b	-	WAA has some dense brush, whereas planned wetland lacks this and other attractors
Uniqueness/Heritage (UH)	NA	1	35	+	Planned wetland is deed restricted
		Target: 1.0	36	+	Planned wetland is research site

FIGURE J-5

Comparison of FCIs and Element Scores (Source: Bartoldus 1994a)

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transit Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
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