Second Edition

Wetland Indicators

A Guide to

Wetland Formation, Identification, Delineation, Classification, and Mapping

CRC Press
Taylor & Francis Group

Ralph W. Tiner

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To my friend and colleague Petrus Lourens Marinus Veneman ("Peter")
for the countless hours shared discussing and investigating
wetlands and teaching wetland delineation.

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Preface to the Second Edition

More than 15 years have passed since this book was first published. At that time, there was enormous controversy in the United States over what was or was not a wetland and what should be regulated by the federal government. Prior to 1989, there was no federal standard for wetland identification and delineation, and when one was established in January 1989, it was only a matter of time until sparks would fly and a political firestorm would ignite, given the potential impact on private property and land development. The impetus for this book was to provide a fairly thorough examination of various options for wetland identification, delineation, and classification, point out some weaknesses in existing procedures (e.g., definition of growing season for use in defining wetland hydrology), help readers better understand how plants and soils respond to prolonged wetness, and provide a rationale for the use of a suite of indicators in the process (see "Preface to the First Edition").

Since the 1990s, much progress has been made in the field of wetland mapping and delineation, especially the latter. We have also learned more about wetlands as research in this field continues to accelerate, particularly because wetlands will be significantly affected by climate change, and their roles in carbon sequestration, methane production, and the global hydrologic cycle are of utmost importance. Also, increasing efforts to restore wetlands has provided opportunities to monitor their development and conduct basic research.

Having been involved with wetland mapping since 1970 and faced with the challenge of attempting to bring order and standardization to wetland identification and delineation practices since the 1980s, I must say that I am generally satisfied with where we, in the United States, are in terms of the techniques now in use to identify wetlands and their boundaries on the ground. The collective efforts of four federal agencies in refining wetland delineation methods are a model for interagency cooperation and good government. The U.S. Army Corps of Engineers has done a remarkable job of bringing more science into the delineation process and working with various agencies to make full use of the variety of indicators that tell us something about how wet an area may be, even when the site does not look obviously wet due to seasonal dryness. Their work on the National Wetland Plant List and continued efforts to examine the use of plants in wetland identification/delineation through its National Technical Committee for Wetland Vegetation are also noteworthy. The USDA Natural Resources Conservation Service (NRCS), working with the National Technical Committee for Hydric Soils, has contributed greatly to improving our knowledge of how soil properties can be used to identify wetlands and their boundaries. Also, the web soil survey of the NRCS is an invaluable tool for wetland delineators. While there is still need for improvement in the wetland mapping field to better utilize advanced remote sensing technologies and provide more current data, the U.S. Fish and Wildlife Service (FWS) should be commended for their efforts to improve the quality of its National Wetlands Inventory products over the years and for making the wetlands data readily available to the public through the wetlands mapper. Finally, the U.S. Environmental Protection Agency's support to states and tribes to promote wetland conservation (including funding wetland mapping initiatives) and assess the condition of wetlands has provided more information on the nation's wetland resources and will hopefully lead to better management.

By these actions and others, the four agencies have helped produce improved tools for identifying and delineating the nation's wetlands while further educating the public on the need to conserve wetlands and to better manage aquatic resources for sustaining their environmental services for generations to come. While the efforts of the listed agencies have had a nationwide impact on wetland delineation and mapping, other federal and state agencies, too numerous to mention, have also contributed significantly to wetland conservation, thus helping improve the status of U.S. wetlands.

While the focus of this edition remains on wetland identification, delineation, classification, and mapping, the book has been updated and expanded to provide readers with a broad understanding of wetlands–how they form and factors affecting vegetation and soil development. This edition brings the wetland delineation procedures up to date, expands the discussion of many topics covered in the original edition, and provides many new references documenting research relevant to wetland identification, delineation, classification, and mapping. I added a chapter on wetland formation and hydrology, since these subjects are fundamental to the understanding and execution of wetland identification, delineation, classification, and mapping. Consequently I added "formation" to the subtitle of the book. I combined original Chapters 1 and 2 into the new Chapter 1 ("Definitions and Concepts"). Some chapters received more attention (Chapters 1, 3, 4, 6, 7, 8, and 10) than others. For example, I did not do any major rewriting of the chapter on hydric soils because the second edition of *Wetland Soils: Genesis, Hydrology, Landscapes, and Classification* (Michael Vepraskas and Chris Craft), was just released by CRC Press. The edits to my chapter on this subject focus on issues pertinent to wetland identification and delineation, especially indicators. I added new material to the wetland mapping chapter but did not address the application of advanced remote sensing techniques since this topic is thoroughly covered by *Remote Sensing of Wetlands: Applications and Advances* (CRC Press, which I coedited with Megan Lang and Vic Klemas). I saw little need to significantly revise the chapter on U.S. wetlands but did update the state wetland areas and added some new references describing the country's wetlands. Finally, in addition to the revised text, this version of *Wetland Indicators* is produced with a large number of color images to better display key wetland characteristics and contains many new figures. This edition should provide readers with a more complete understanding of the topics covered and a strong foundation for their knowledge on delineating and mapping wetlands and will, hopefully, stimulate interest in promoting wetland conservation and restoration.

Ralph W. Tiner

Preface to the First Edition

The existence of wetlands has been and remains very important to people around the globe. Since the dawn of mankind, wetlands have provided a wealth of materials for food, fiber, and shelter that have supported many communities. In fact, the Tigris–Euphrates delta, long considered to be the "cradle of civilization," is an enormous wetland complex that has sustained hundreds of generations of families. The vital link between wetlands and water has created conditions that generate a host of ecosystem functions critical to the existence of many plants and animals and that also benefit humankind in many ways. Some wetlands are among the most diverse and productive natural systems on the planet, thereby serving as important places for the conservation of biodiversity. This productivity has also benefitted human civilizations. The fertile soils of many wetlands, especially those on floodplains, lured people to these areas who then put many wetlands into agricultural production. The staple crop for much of the world's population—rice—is a wetland plant. The location of many wetlands along rivers and other waterways was another important attraction as these waters served as transportation corridors facilitating trade, connecting one community to another. These uses led to the establishment of villages, towns, and cities near many wetlands. In other cases, they played a strategic role in military operations as roads through the larger wetland systems were critical arteries for supplying armies with supplies and equipment. These are but a few of the reasons why people the world over have been interested in wetlands and their whereabouts.

As human cultures grew from small tribes reliant on natural subsistence to the agriculturally dependent and later the industrialized civilizations, human attitudes toward wetlands undoubtedly changed. With less dependence on natural products, the majority of people in these cultures likely viewed wetlands as wastelands whose best use could only be attained through conversion to agriculture or to *dry land* for development. Later, as the quality of the natural environment began to noticeably deteriorate (e.g., increasing water pollution, degrading air quality, more flooding of cities and towns, and accelerating wetland destruction), more Americans began to again appreciate the values of natural wetlands. In the United States today, wetlands are recognized as one of the nation's most valuable natural resources, providing valued functions such as water quality filtration, flood storage, erosion control, and shoreline stabilization. Wetlands also are essential habitats for many fish and wildlife species and areas where a variety of natural products (e.g., timber, wild rice, cranberries, blueberries, and peat moss) are produced. Due to these and other functions, wetlands are important enough for society to be concerned about their alteration (i.e., loss and degradation).

In the United States, public recognition of the natural functions of wetlands and concern over accelerating wetland losses in the 1950s and 1960s led to the establishment of federal and state legislation to protect or at least attempt to minimize the adverse environmental impacts of development. The Federal Clean Water Act is the main federal law controlling the exploitation of wetlands in the United States. Although this law is not a wetland protection law per se, it regulates wetland development due to the role of wetlands in maintaining water quality. Consequently, the federal government now regulates uses of wetlands that would adversely affect the quality of America's waters. Although the Clean Water Act has done much to improve the plight of wetlands over the past two decades, this law is not a wetland protection law, and so many wetlands that are not important to water quality, but are vital to unique forms of plants and animals, are not currently protected by federal law. In contrast, numerous states have passed *wetland protection laws* specifically designed to protect the multiple functions that wetlands provide, including fish and wildlife habitat. In the early to mid-1960s, Massachusetts was the first state to pass wetland protection acts, first for coastal wetlands, and shortly thereafter for inland wetlands. Other coastal states followed this lead; today most states have laws that regulate uses of tidal wetlands. Several others have also passed similar laws for inland wetlands. Also, in more urban and expanding suburban areas, many local governments have established zoning ordinances to control development in wetlands. All of these laws and regulations now make it vitally important to know how to identify wetlands and their boundaries.

To meet their wetland protection mandates, federal and state governments had to develop techniques to aid in the identification and delineation of wetlands. These methods evolved over time with the earliest approaches using rather simple assessment techniques. As the science of wetland ecology grew in the 1970s and 1980s, more information on wetland plants, soils, and hydrology became available. This increased knowledge helped better articulate the concept of wetlands and necessitated improvements in wetland identification methodologies. Consequently, the extent of lands recognized as "wetlands" for regulatory purposes increased in geographic scope, with a rather obvious disapproving response from some segments of the regulated community.

During the past decade, there has been much public discourse and political rhetoric on what is a wetland (e.g., how wet should an area be in order to qualify as wetland) and how wetlands should be regulated. While the latter debate will undoubtedly continue, there appears to be widespread agreement among the scientific communities on what constitutes a wetland. Since 1989, some politicians have been proposing different definitions of wetlands to curtail federal jurisdiction under the Clean Water Act. In 1993, the Congress provided funds to the U.S. Environmental Protection Agency to commission a National Research Council (NRC) investigation of the wetland delineation issue. The NRC established the Committee on Characterization of Wetlands, a 17-member committee composed mostly of scientists (with expertise in wetlands, hydrology, soil science, and mapping), to review and evaluate the effects of alternative methods of wetland delineation and to summarize the scientific understanding of wetland functions with respect to wetland delineation. After two years of study, the NRC published its report, "Wetlands Characteristics and Boundaries", in 1995. This document represents the view of the scientific community on wetlands. One of the report's major findings was that the federal government had, in general, been using appropriate scientific techniques for identifying wetlands. They recommended that a new federal wetland delineation manual be prepared because their study found more efficient ways of identifying wetlands in lieu of the federal government's current three-parameter/criteria procedures. The report made numerous other recommendations on how to improve the current system. In spite of a government proclamation in President Clinton's *No-Net-Loss* policy of using the best science in regulating wetlands, the federal government has yet to pursue development of a new manual with more efficient and effective methods based on current scientific knowledge.

In the past quarter century, wetlands have received more scientific study than in all the years before. More research articles have been published, several journals and newsletters are devoted to wetlands, and wetland maps have been produced by the federal government, many states, and some local communities. As a result of these efforts, wetlands are better understood, the concept of wetland is better explained, and the techniques for wetland identification and delineation are more refined and scientifically sound. The indicators used to identify wetlands have moved from a traditional dependence on plants and plant communities to an approach that considers a combination of factors including vegetation, soils, and signs of hydrology.

This book is written to aid readers in understanding the current concept of wetland and the use of various plant, soil, and other indicators for wetland identification in the United States and in learning how to identify, describe, classify, and delineate wetlands. The specific purposes of this book are (1) to review the concept of wetland beginning with a review of wetland definitions (from the late 1800s up to the present), (2) to examine the use of wetland indicators and provide a background on the science behind them, (3) to review current wetland identification and delineation techniques, (4) to discuss problem situations for wetland delineation and offer technical guidance for their resolution, (5) to review wetland classification systems, (6) to introduce the diversity of wetland plant communities across the country, and (7) to address wetland photointerpretation and mapping.

In discussing wetland indicators, this book largely focuses on plants, soils, and other signs of wetland hydrology in the soil or on the surface of wetlands. The significance of learning to recognize certain landscape positions and landforms that facilitate wetland formation is also mentioned.

The book does not emphasize wetland animals as possible indicators of wetlands, with a few exceptions (e.g., aquatic invertebrate remains and crayfish burrows). Yet it must be recognized that the presence of many wetland-dependent animals (e.g., beaver, muskrat, wading birds, waterfowl, shorebirds, clams, mussels, and other aquatic invertebrates) also suggests the existence of wetlands. Due to their mobility, however, many of these animals may be found in uplands or deepwater habitats, so their presence in a given area at a particular point in time does not make the area a wetland. In addition, they tend to be associated with the more obvious, wetter wetlands where water is present much of the year, so their use in wetland identification is of limited added value.

The information presented in this book, coupled with the NRC's findings, should give readers a fairly thorough understanding of the current state of knowledge about the science behind wetland delineation and improved insight for evaluating the strengths and weaknesses of current delineation practices. Overall, it is hoped that this book will help individuals interested in wetland delineation strengthen their knowledge about wetlands and the use of various indicators and boost their confidence in applying professional judgment when making difficult wetland determinations.

This book should be a must read for anyone involved with wetland regulations and delineation. Both practicing wetland delineators and others seeking to become delineators should find that it provides critical insight into the development and significance of hydrophytic vegetation, hydric soils, and other wetland indicators and their use for wetland identification and delineation. Chapters on U.S. wetlands and wetland mapping and photointerpretation provide the reader with an understanding of the variety of plant communities associated with America's wetlands and some offsite tools to help identify them. The book may also serve as an supplemental textbook for upper-level undergraduate and graduate courses in wetland ecology, especially those emphasizing applied wetland science (i.e., wetland identification, classification, delineation, and mapping).

In writing this book, I became more concerned that certain wetlands are not being identified as "regulatory wetlands" because they fail to exhibit the suite of necessary indicators approved by some regulatory agencies. Consequently, these types are not protected by current laws. For some of them, more information on their functions may be required to justify increased federal or state protection (e.g., marginally wet flatwoods), yet others have widely recognized values unique to these ecosystems. For example, West Coast vernal pools and small isolated vernal pools in eastern forests are vital areas for preserving biodiversity and critical breeding grounds for many amphibians, respectively. Nonwetland riparian habitats intricately linked to contiguous wetland and aquatic systems are also vital to local wildlife and migratory species. These areas are rapidly disappearing and new legislation and/or government initiatives will be required to protect them by some combination of regulation, acquisition, and other means that promote private stewardship. Currently, wetlands are regulated nationally, largely under the Clean Water Act, due to their water quality maintenance function. Yet, recognizing the importance of preserving diverse ecosystems and the overall importance of wetlands (and associated riparian habitats) along rivers and streams and preserving the integrity of these aquatic ecosystems and fish and wildlife dependent on these habitats, our nation's leaders need to muster the courage and support to establish an act on national wetlands and riparian habitat conservation. This will help conserve, restore, and enhance wetlands and riparian habitat for their intrinsic values, not simply for their flood storage and water quality functions. The quality of the natural world around us is of important societal value that needs to be addressed in natural resource management.

Ralph W. Tiner
Wetland Ecologist

Acknowledgments

Since this book is a revision of the original one published in 1999, I need to acknowledge people who have helped me with both versions; see the addendum for an adaptation of the original acknowledgments.

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Author

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Professor Tiner has been identifying and mapping wetlands since 1970 when he helped conduct on-the-ground mapping of Connecticut's tidal wetlands for one of the nation's first state tidal wetland regulatory programs. Since then, he has mapped wetlands from Maine through Virginia for the National Wetlands Inventory and in South Carolina and other local areas of the country. He has developed a set of hydrogeomorphic descriptors to be added to NWI data to predict wetland functions at the landscape level. He has written over 200 publications on wetland topics such as wetland status and trends, wetland identification, classification, mapping, restoration, hydric soils, and wetland plants. Among his several books, the following are the more popular publications: *Field Guide to Coastal Wetland Plants of the Northeastern United States* (University of Massachusetts Press; 1987), *Field Guide to Nontidal Wetland Identification* (U.S. Fish and Wildlife Service and Maryland Department of Natural Resources; 1988), *Field Guide to Coastal Wetland Plants of the Southeastern United States* (UMass Press; 1993), *In Search of Swampland: A Wetland Sourcebook and Field Guide* (Rutgers University Press; 1998, 2005), *Wetland Indicators: A Guide to Wetland Identification, Delineation, Classification, and Mapping* (Lewis Publishers; 1999), *Field Guide to Tidal Wetland Plants of the Northeastern United States and Neighboring Canada* (UMass Press; 2009), *Tidal Wetlands Primer: An Introduction to their Ecology, Natural History, Status, and Conservation* (UMass Press; 2013), and *Remote Sensing of Wetlands: Applications and Advances* (CRC Press; 2015). He also coauthored with Peter Veneman—*Hydric Soils of New England* (UMass Cooperative Extension; 1987), the first practical guidebook for identifying U.S. hydric soils. He is editor of the Society of Wetland Scientists journal—*Wetland Science & Practice*—treasurer for the U.S. National Ramsar Committee, and a lifetime member of the Society of Wetland Scientists.

1 Wetland Definitions and Concepts for Identification and Delineation

INTRODUCTION

The term "wetland" has no single, scientific, universal meaning as it has been applied by scientists from different fields of study, resource agencies with varied interests, conservation organizations, and others to describe land that is wetter than dryland. Since the practices of wetland identification and delineation as well as classification are grounded on how "wetland" is defined, this book begins with a discussion of definitions and then addresses some key concepts in applying the definition on the ground. The latter discussion focuses on applications in the United States since many laws are in place that require on-site identification of wetlands and delineation of their boundaries, and as a result, much thought has been given to the topic since the laws regulate use of private property.

DEFINITIONS

Wetland is a generic term used to define the universe of wet habitats including marshes, swamps, bogs, fens, and seasonally waterlogged areas. Wetlands are environments subject to permanent or periodic inundation or prolonged soil saturation sufficient for the establishment of hydrophytes[*] and/or the development of hydric soils or substrates[†] unless environmental conditions are such that they prevent them from forming. These are the places (e.g., landforms) where a recurrent excess of water imposes controlling influences on all biota (plants, animals, and microbes)—this may be a seasonal and more predictive occurrence or an episodic one that is less predictable. Given the regional differences in hydrologic regimes, climate, soil-forming processes, and geomorphologic settings, a vast assemblage of wetland plant communities and hydric soil types have evolved worldwide. Numerous terms have been applied to individual wetlands because of these differences. Some common wetland types in North America include salt marsh, freshwater marsh, tidal marsh, alkali marsh, fen, wet meadow, wet prairie, alkali meadow, shrub swamp, wooded swamp, bog, muskeg, wet tundra, pocosin, mire, pothole, playa, salina, salt flat, tidal flat, vernal pool, bottomland hardwood swamp, river bottom, lowland, mangrove forest, and floodplain swamp (Figure 1.1). Although commonly used, many of these terms do not have universally accepted definitions and may mean different things to different people (e.g., Locky et al., 2005).

Within regions, wetlands naturally form in places on the landscape where surface water periodically collects for some time and/or where groundwater discharges, at least seasonally, sufficient to create waterlogged soils. Common wetland landforms include (1) depressions surrounded

* Hydrophytes are individual plants growing in water or on substrates (e.g., soils) that are periodically subject to anaerobic conditions due to excessive wetness.

† Hydric soils are soils that are saturated at or near the surface (by flooding or high groundwater tables) usually frequent and long enough to promote the development of anaerobic reducing conditions that affect plant growth and promote the establishment of erect (self-supporting) hydrophytes. Hydric substrates are permanently or nearly permanently inundated or saturated substrates lacking erect hydrophytes; they are mostly nonvegetated areas (e.g., the bottoms of permanent waterbodies) but may be vegetated with submergent species or floating-leaved plants.

FIGURE 1.1 Some examples of common wetland types in the United States: (a) tidal salt marsh, (b) freshwater marsh, (c) fen or wet meadow, (d) shrub bog (Courtesy of Bill Zinni), (e) southern forested wetland, and (f) inland salt flat (Courtesy of Lindsey Lefebvre).

by upland and with or without a drainage stream, (2) relatively flat low-lying areas (floodplains) along major waterbodies (e.g., rivers, lakes, and estuaries) usually with fluctuating water levels, (3) shallow water of protected (low-energy) embayments and slow-flowing channels, (4) broad flat areas lacking drainage outlets (e.g., interstream divides), (5) vast expanses of arctic and subarctic lowlands where a permafrost layer occurs near the surface (muskegs), (6) sloping terrain below the sites of groundwater discharge (e.g., springs, seeps, toes of slopes, and drainageways), (7) slopes below melting snowbeds and glaciers, and (8) flat or sloping areas adjacent to bogs and subject to paludification processes in regions with cold, wet climates (see Chapter 2 for details).

While most wetlands tend to develop in the areas mentioned earlier, some wetlands form on steep slopes.

Some people have said that wetland is a euphemism for "swamp" that has evoked negative feelings due to its usage in literature and everyday speech (National Research Council, 1995). If this is true, it is likely an unintentional euphemism, since it is clear that the term "wetland" is simply a combination of two words, "wet" and "land," that simply describes the overall condition of the land. Such land has water present at or near the surface for significant periods that affect land use. It may be wet too long to grow most crops without some artificial drainage or long enough to pose significant constraints on construction activities (e.g., cannot build without filling and/or draining). The term "wetland" has been in use for some time. Shaler (1890) referred to "the wet lands of the Old World" when comparing the significance of sphagnum growth in the United States to Europe. The common early usage of "wetland" is further witnessed by Dachnowski's complaint that the usage of too many generic terms, including wetland, overflowed lands, swampland, and muck, was hindering scientific studies of peat (Dachnowski, 1920).

Wetland does not imply that the land has to be permanently flooded. If this was the case, such lands would simply be called "submerged lands" or "flooded lands" rather than wetland. Instead, wetland suggests that land that is noticeably wet for various periods—land that is periodically wet and, when not, may be dry or at least exposed to air for some time. Wetlands include both periodically and permanently flooded lands (see Chapter 2), yet the latter are typically restricted to shallow water areas that often support either free-standing plants like reeds, shrubs, or trees or rooted floating-leaved aquatic plants like water lilies, unless wave energy and other factors prevent their colonization.

When considering periodically wetlands, the frequency and duration of flooding and/or soil saturation (near the surface) need to be taken into account. After all, it is the recurring prolonged wetness that exerts significant stress on vegetation to exclude most plants from growing in wetlands. The fundamental questions for defining wetlands, therefore, include the following: (1) How long and at what frequency must an area be wet? (2) Must wetness occur during the growing season or is nongrowing season wetness also important to consider? (3) Should wetness occur to the ground surface, or if not, what soil depth is critical? These questions should be kept in mind when reviewing existing wetland definitions. The answers to these questions are vital to developing criteria and a set of reliable indicators (e.g., plant, animals, and soils) to validate the occurrence of wetland.

Numerous wetland definitions have been developed for various purposes. The earliest wetland definitions were created for scientific studies or management purposes, with the more widely used ones created to serve as the foundation for wetland mapping projects. Since the 1960s, other definitions have been formulated to establish limits on what "wet" lands should be regulated through various wetland laws and government wetland regulations and policies.

SHALER'S WETLAND DEFINITION (1890)

One of the earliest reports on U.S. wetlands was Nathaniel Shaler's *General Account of the Freshwater Morasses of the United States* published in 1890. This U.S. Geological Survey report focused on inundated lands and included what is perhaps the nation's first national wetland classification system (see Chapter 8). In preparing a table with the estimated acreage of inundated lands east of the Rockies, Shaler included the following definition of "swamp":

> all areas … in which the natural declivity is insufficient, when the forest cover is removed, to reduce the soil to the measure of dryness necessary for agriculture. Wherever any form of engineering is necessary to secure this desiccation, the area is classified as swamp.

In calculating the total wetland acreage, he also included "areas of alluvial lands subject to inundations in the tillage season to such an extent that agriculture is unprofitable until the land is drained or diked." Consequently, Shaler's concept of wetland (swamp) is quite broad and includes consideration of the effect of soil wetness on land use, namely, farming.

SCIENTIFIC WETLAND DEFINITIONS

Depending on the field of study, wetland definitions may focus on particular attributes as noted by Lefor and Kennard (1977) in their review of inland wetland definitions. A hydrologist's definition of wetlands would focus on the fluctuations in the water table and on the frequency and duration of flooding. A soil scientist's definition might center on the presence of certain soils, mainly poorly drained and very poorly drained soils, plus soils that are frequently inundated for long or very long periods of time that affect crop production (e.g., soils that are too wet to grow corn and other crops without artificial drainage). A botanist's definition would emphasize the occurrence of certain plant species and certain plant communities and the wetness conditions promoting their colonization. A fish and wildlife biologist's definition might stress the characteristics associated with fish spawning and nursery grounds and with wetland-dependent wildlife like waterfowl, shorebirds, wading birds, beaver, muskrat, frogs, salamanders, turtles, and alligators. A civil engineer's definition of wetland would likely highlight the wetness conditions in the soils that affect the ability of the substrate to support construction of roads, bridges, buildings, and similar structures. Thus, a plethora of wetland definitions could be developed based on different areas of expertise or interest.

Current wetland definitions are largely biologically based, since professionals in wildlife biology and botany were among the first to recognize the values that wetlands contribute to society in their natural, unaltered state. Since vegetation patterns are readily observed in most cases, wetland definitions tend to emphasize certain plant communities associated with waterbodies or waterlogged soils. Such communities provide vital habitats for fish spawning and nurseries and support unique forms of wildlife and plant species, and depending on their landscape position and wetness properties, they provide other valued functions such as flood storage, nutrient recycling, water quality renovation, and shoreline stabilization (e.g., Tiner, 2013; Mitsch and Gosselink, 2015).

The most widely used of the scientific definitions in the United States were developed by the U.S. Fish and Wildlife Service (FWS), which has a long history of interest in wetland conservation given their significance as critical habitats for many of the nation's fish and wildlife species. In order to provide more effective management of these habitats, the FWS has been monitoring the status of wetlands in the country since the 1950s. Two wetland definitions were developed to aid in performing inventories of U.S. wetlands. More recently, another scientific wetland definition was formulated by the National Research Council's (NRC) Committee on Characterization of Wetlands as the reference for conducting a review of the federal government's wetland delineation practices. Canada and other countries have developed wetland definitions for their own inventories. These definitions are briefly discussed later.

Evolution of the U.S. Fish and Wildlife Service Wetland Definition

During the 1950s and 1960s, the FWS initiated a nationwide inventory of wetlands important to waterfowl and follow-up surveys of key areas (e.g., coastal wetlands). In conducting these inventories, the FWS used the Martin et al. (1953) wetland classification system based on the following definition:

> Wetlands are "lowlands covered with shallow and sometimes temporary or intermittent waters. They are referred to by such names as marshes, swamps, bogs, wet meadows, potholes, sloughs, and river-overflow lands. Shallow lakes and ponds, usually with emergent vegetation as a conspicuous feature, are included in the definition, but the permanent waters of streams, reservoirs, and deep lakes are not

included. Neither are water areas that are so temporary as to have little or no effect on the development of moist-soil vegetation. Usually these temporary areas are of no appreciable value to the species of wildlife considered in this report."

Shaw and Fredine (1956)

While the focus on habitat for certain wildlife (mainly waterfowl) and vegetation is clear, the definition recognizes the variability of the hydrology (shallow to temporary or intermittent waters) in wetland habitats. Most of the wetland types listed are largely vegetated areas. Shallow waterbodies are included in the definition, whereas deeper waterbodies are omitted. This definition was also adopted for use by the USDA Soil Conservation Service for determining when it was appropriate for providing technical assistance for wetland drainage on farms. The Martin et al. system was criticized for inconsistent application, ignoring ecologically significant differences such as the distinction between fresh and subsaline wetlands and lumping dissimilar wetland types like boreal spruce bogs with southern cypress-gum swamps (e.g., Leitch, 1966; Stewart and Kantrud, 1971; Cowardin et al., 1979).

In 1974, the FWS established the National Wetlands Inventory Project to map the nation's wetlands for resource conservation purposes. For this survey, wetland maps were to be prepared to inform the public on the location of these significant natural resources. To accurately map these resources, the FWS had to determine where along the natural soil moisture continuum wetland ends and upland begins. An ecologically based definition was constructed by the FWS to help ensure accurate and consistent wetland determinations. The FWS did not attempt to legally define wetland, since it was recognized that each state or federal regulatory agency may define wetland somewhat differently to suit its administrative purposes. A science-based definition would serve more uses and users outside the FWS.

In January 1975, the FWS brought together wetland scientists from across the country to review the Martin et al. system in light of 20 years of new information on wetlands and experiences applying the system. They concluded that a new classification should be developed (Sather, 1976). In July 1975, the FWS sponsored a wetland classification workshop in College Park, Maryland. During this meeting, wetland scientists from federal and state agencies, the Canadian government, and academia discussed wetland programs, concepts, and classification and reviewed a draft classification by Lewis Cowardin of the FWS and Virginia Carter of the U.S. Geological Survey. Participants indicated that many people regarded lakes and ponds as wetlands and that the seaward limit of wetland might be considered to be the edge of the continent shelf. There was widespread agreement that wetlands should be defined by plants, soils, and hydrology (water regimes) and that the definition should be general (not specifying individual plants or soil types), concise, easily understood, and scientifically based. Agricultural lands that had wetland water regimes and soil types should be included in the definition. Also, the presence of existing vegetation (e.g., agricultural crops or certain trees or herbaceous species not typical of wetlands) should not prevent classification of such areas as wetlands if their water regime and soils were typically wetland in nature. Western scientists felt that riparian vegetation should be included in the wetland definition. Questions also were raised on whether the concept of wetland should include the entire 100-year floodplain as wetlands or at least in the wetlands inventory, recognizing the public interest in these resources (Sather, 1976). After this meeting, a four-person team (Cowardin, Carter, Frank Golet, and Ted LaRoe) developed the FWS's interim wetland classification system (Cowardin et al., 1976) that included the following wetland definition for review:

Wetland is land where an excess of water is the dominant factor determining the nature of soil development and the types of plant and animal communities living at the soil surface. It spans a continuum of environments where terrestrial and aquatic systems intergrade. For purposes of this classification system, *wetland* is defined more specifically as land where the water table is at, near, or above the land surface long enough each year to promote the formation of hydric soils and to support the growth

> of hydrophytes, as long as other environmental conditions are favorable … In certain wetland types, vegetation is absent and soils are poorly developed or absent as a result of frequent and drastic fluctuations of surface-water levels, wave action, water flow, turbidity, or extremely high concentrations of salts or other substances in the water or substrate. Wetlands lacking vegetation and hydric soils can be recognized by the presence of surface water at some time during the year and their location within, or adjacent to, vegetated wetlands or aquatic habitats.

An April 1977 version contained a similar definition with only minor revisions (Cowardin et al., 1977a). This version was made available for public review and comment. In October 1977, the FWS produced an operational draft version of its classification system for initiating wetland mapping (Cowardin et al., 1977b). The definition is essentially the same as the 1976 version except that the first two sentences were eliminated from the definition and moved to the concepts discussion preceding the definition:

> Wetland is defined as land where the water table is at, or near or above, the land surface long enough to promote the formation of hydric soils or to support the growth of hydrophytes. In certain types of wetlands, vegetation is lacking and soils are poorly developed or absent as the result of frequent and drastic fluctuations of surface-water levels, wave action, water flow, turbidity, or high concentrations of salts or other substances in the water or substrate. Such wetlands can be recognized by the presence of surface water or saturated substrate at some time during each year and their location within, or adjacent to, vegetated wetlands or deep-water habitats.

U.S. Fish and Wildlife Service Wetland Definition

After using the operational draft for a couple of years and receiving public input, the FWS amended its classification and revised its wetland definition (Cowardin et al., 1979). The following definition has served as the FWS's official wetland definition for nearly four decades and continues to be used for wetland mapping:

> Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification, wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year.

In defining wetlands from an ecological standpoint, the FWS emphasizes three key attributes of wetlands: (1) hydrology, the degree of flooding or soil saturation, (2) wetland vegetation (hydrophytes), and (3) hydric soils. Although not mentioned specifically in the definition, the document's discussion of concepts and definitions also makes reference to animal communities stressed by prolonged saturation. The concept of wetland is a broad-based ecological one recognizing both plants and animals adapted to these conditions.* All areas considered wetlands must have enough water at some time during the year to stress plants and animals not adapted for life in water or saturated soils. Most wetlands have hydrophytes and hydric soils present, yet many are nonvegetated (e.g., tidal mudflats). The FWS in cooperation with the U.S. Army Corps of Engineers (Corps), the U.S. Environmental Protection Agency (EPA), and the USDA Soil Conservation Service prepared a list of plants occurring in the nation's wetlands and revised the list periodically (Reed, 1988, 1997) until it passed the list onto the U.S. Army Corps of Engineers for maintenance and updating due to the critical use of the list for

* In fact, some wetland types are formed by animal communities, for example, coral, mollusk, and worm reefs and numerous animals are listed as dominant types for unconsolidated shores (a type of nonvegetated wetland).

jurisdictional wetland determinations and required regulatory reviews.* Likewise, the USDA Natural Resources Conservation Service (NRCS; formerly the Soil Conservation Service) developed a national list of hydric soils, which also has been updated periodically (www.nrcs.usda.gov/wps/portal/nrcs/main/soils/use/hydric). These lists and a compilation of field indicators of hydric soils have greatly contributed to a better understanding of wetlands and to standardizing procedures for their identification.

According to the FWS definition, wetlands typically fall within one of the following four categories: (1) areas with both hydrophytes and hydric soils (e.g., marshes, swamps, and bogs); (2) areas without hydrophytes, but with undrained hydric soils (e.g., farmed wetlands); (3) periodically inundated or permanently flooded areas without soils but with hydrophytes (e.g., seaweed-covered rocky intertidal shores and aquatic beds on hydric substrates in shallow water); and (4) periodically flooded or saturated areas without soil and without hydrophytes (e.g., gravel bars and tidal mudflats). The latter two areas must be wet at some time during the growing season of each year (i.e., a year of normal precipitation).

Various altered wetlands also are contained within the FWS wetland definition. Farmed wetlands are wetlands where "the soil surface has been mechanically or physically altered for the production of crops, but hydrophytes will become reestablished if farming is discontinued." Such areas typically possess hydric soils and wetland hydrology. Partly drained wetlands still retain some degree of wetland hydrology, sufficient to support the continued growth of hydrophytes. Artificial wetlands are wetlands created either purposefully or accidentally. They include vegetated wetlands built in tidal areas by deposition of dredged spoil or constructed in impoundments or excavated basins in nontidal areas, and nonvegetated wetlands such as rocky shores (e.g., jetties and groins) that provide artificial habitats for marine life. Other altered wetlands are excavated, impounded, or diked wetlands.

Drainage activities in wetlands can modify the hydrology to the point where the area is no longer functioning as a wetland. Effectively drained hydric soils that are no longer capable of supporting hydrophytes due to a major change in hydrology are not considered wetland. Areas with effectively drained hydric soils are, however, good indicators of historic wetlands, which may be suitable for restoration.

The FWS definition includes shallow waters as wetland but does not include permanently flooded deepwater areas. These deeper waterbodies are defined as deepwater habitats, since water and not air is the principal medium in which dominant organisms live (Cowardin et al., 1979). Along the coast in tidal areas, the break between wetland and deepwater habitat begins at the extreme spring low tide level. In nontidal freshwater areas, this split now starts at a depth of 8.2 ft (2.5 m; originally it was 6.6 ft/2.0 m—revised by the Wetlands Subcommittee of the Federal Geographic Data Committee; FGDC Wetlands Subcommittee, 2013)† because shallow water areas are often vegetated with emergent wetland plants (e.g., bur-reeds) or floating-leaved rooted vascular plants (e.g., water lilies) (Figure 1.2).

National Research Council Wetland Definition

During the early 1990s, there was considerable interest and controversy in wetland delineation when the U.S. federal government, namely, the Corps and EPA, decided to apply consistent standards for identifying and delineating wetlands for jurisdiction under the Clean Water Act. This action had the effect of significantly increasing the geographic scope of public and private lands subject to such regulation in regions where substandard procedures had been used to determine jurisdiction. Due to

* In 2006, the Corps, EPA, FWS, and NRCS signed a memorandum of agreement that transferred responsibility for updating the "National List of Plant Species that Occur in Wetlands" from the FWS to the Corps; this list is now called the "National Wetland Plant List" (http://rsgisias.crrel.usace.army.mil/NWPL/).

† The Wetlands Subcommittee of the Federal Geographic Data Committee updated the Cowardin et al. system in 2013; only minor changes were made to the classification system.

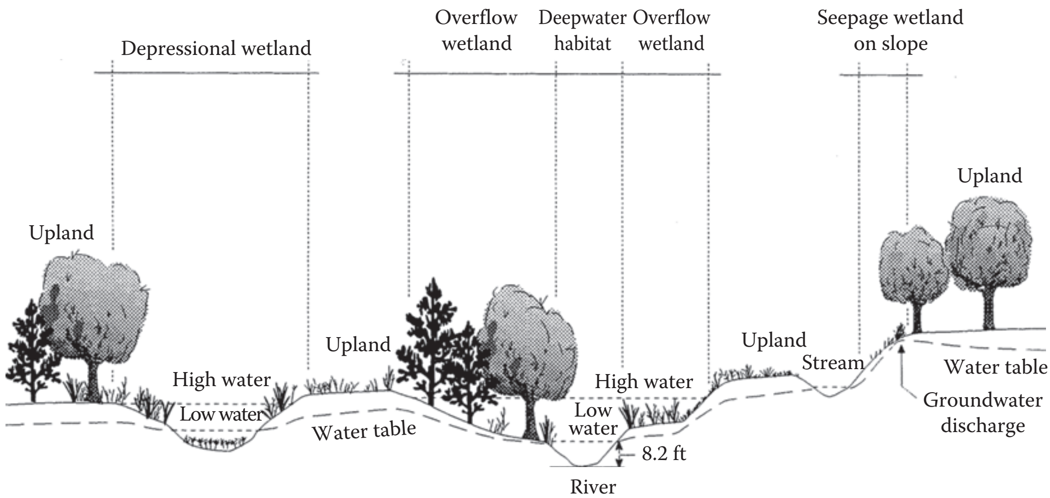

FIGURE 1.2 Schematic diagram showing wetlands, deepwater habitats, and uplands on the landscape. Note that in freshwater systems, wetlands include shallow water areas less than 8.2 ft (2.5 m) at mean low water (according to the Cowardin et al. system as amended by the Federal Geographic Data Committee; FGDC, 2013). In tidal systems, wetlands extend seaward to the extreme low spring tide mark, thereby including all areas that are periodically exposed by the tides but not permanently inundated areas. (Adapted from Tiner, R.W. and Burke, D.G., *Wetlands of Maryland*, U.S. Fish and Wildlife Service, Region 5, Hadley, MA and the Maryland Department of Natural Resources, Annapolis, MD, 1995, Cooperative publication.) *Note*: The maximum depth of a freshwater wetland was changed around 2012 from 6.6 to 8.2 ft.

significant opposition from the development and the agricultural communities, political pressures mounted to the extent that certain members of Congress and the Bush Administration attempted to change the definition of wetland to reduce the scope of federal jurisdiction. During this time, environmental groups lobbied Congress and recommended that they fund a study of wetland delineation. The study would focus on the scientific foundation for wetland delineation and review existing methods used by the federal government to determine their scientific fitness. In 1993, Congress provided funding to the EPA for the NRC to conduct such a study. A 17-member committee (representing the academic community, industry, environmental community, and legal profession)—the Committee on Characterization of Wetlands—was assembled to undertake this study. The results of their 2-year study are presented in *Wetlands: Characteristics and Boundaries* (National Research Council, 1995).

In order to initiate its study, the Committee needed a definition to provide the framework for its investigation. They drafted the following reference definition:

> A wetland is an ecosystem that depends on constant or recurrent, shallow inundation, or saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation, or saturation at or near the surface and the presence of physical, chemical, and biological features reflective of recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. These features will be present except where specific physiochemical, biotic, or anthropogenic factors have removed them or prevented their development.

This definition is consistent with the official FWS definition. Both definitions recognize that hydrology, soils/substrates, and vegetation are key elements, with added attention given to biota in general (including animals) in the NRC definition. They both speak to the variability of hydrology ranging from permanent water (constant inundation or soil saturation) to periodic wetness (recurrent shallow inundation or saturation). Both emphasize that when it comes to soil saturation, it is saturation "at or near the surface" that determines wetlands.

Canadian National Wetland Definition

In 1987, the National Wetlands Working Group of the Canada Committee on Ecological Land Classification defined wetlands in its national wetland classification for Canada.* The group was represented by technical wetland experts from across the country:

> Wetland is defined as "land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation, and various kinds of biological activity which are adapted to a wet environment."
>
> **National Wetlands Working Group (1987)**

Two basic types of wetlands are recognized, organic wetlands on peat and muck soils and mineral wetlands including mineral soils beneath shallow water, Gleysols, and other mineral soils modified by water-control structures or that "are tilled and planted but which, if allowed to revert to their original state, become saturated for long periods and are then associated with wet soils (e.g., Gleysols) and hydrophytic vegetation." This definition also is consistent with U.S. wetland definitions of the FWS and NRC and, like the latter, also stresses biological activity resulting from prolonged wetness as an indicator of wetlands. Canada uses this definition for its national wetland conservation policy (1991) that directs all federal departments to the goal of no net loss of wetland functions on federal lands or areas affected by federal programs or activities. This policy added the following to the definition:

> Wetlands include bogs, fens, marshes, swamps and shallow waters (usually 2 m deep or less) as defined in The Canadian Wetland Classification System published by the National Wetlands Working Group of the Canada Committee on Ecological Land Classification (1987).

Some provinces have adopted the definition or something very similar for wetland conservation policies (e.g., Prince Edward Island and Alberta) but may have other definitions for regulating wetlands under environmental protection or Clean Water Act laws (e.g., watercourses and wetland alteration regulations).† Examples of the latter definitions are included in the discussion of regulatory definitions.

Other Wetland Definitions for Conservation and Assessment

Wetlands have been defined in other countries largely by scientists and natural resource agencies interested in the ecological significance of these areas as habitats for waterbirds and other animals and potential land uses. Climate change has spurred much interest in wetlands. Modelers need to know the extent of surface water and wetlands globally for predicting the impact of climate change on the Earth's hydrology, carbon dioxide cycling, and methane emissions. To determine global wetland extent, scientists must utilize advanced remote sensing techniques and this application has produced the need for a common definition. Researchers in this field have proposed a wetland definition for consideration.

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* This classification system is now in its second edition; National Wetlands Working Group (1997) edited by Warner and Rubec.

† As of November 2015, the province of Ontario is drafting a wetland conservation policy for public review.

Ramsar Wetland Definition

The Convention on Wetlands, commonly known as the Ramsar Convention, an international government body of more than 90 countries, interested in worldwide wetland conservation, developed the following definition:

> Wetlands are "areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed 6 m." Wetlands "may incorporate riparian and coastal zone adjacent to wetlands, and islands or bodies of marine water deeper than 6 m at low tide lying within the wetlands."
>
> **Ramsar Information Bureau (1998)**

This definition is quite broad, extending the waterward depth of wetlands to 19.7 ft (6 m) in marine environments with no depth limit specified for lentic and lotic systems,* thereby including many "deepwater habitats" of the U.S. definition in the Ramsar concept of wetland. It also recognizes that wetland ecosystems may contain other habitats (e.g., riparian habitats and deep open water areas) as vital components that are virtually inseparable from the wetland itself. Although not explicit in the definition, it also includes "human-made wetlands" (Ramsar Information Bureau, 1998). Fish and shrimp ponds, farm ponds, irrigated agricultural land (e.g., rice paddies), salt pans, reservoirs, gravel pits, sewage farms, and canals are within the scope of this wetland definition. Many countries have adopted this definition to promote wetland conservation in their lands and to designate "wetlands of international importance" in accordance with the terms of the Ramsar Convention.

Australian Wetland Definitions

A review of Australian wetlands by Paijmans et al. (1985) contained the following definition:

> Wetlands are "land permanently or temporarily under water or waterlogged. Temporary wetlands must have surface water or waterlogging of sufficient frequency and/or duration to affect the biota. Thus, the occurrence, at least sometimes, of hydrophytic vegetation or use by waterbirds are necessary attributes. This wide definition includes some areas whose wetland nature is arguable, notably land subject to inundation but having little or no hydrophytic vegetation, and bare 'dry lakes' in the arid interior."

This definition emphasizes hydrology and wetland biota, specifically hydrophytic vegetation and waterbirds. It also, however, recognizes that wetlands include both vegetated and nonvegetated periodically wet areas. Moreover, the latter types are expected due to the dry climate of the country's interior. Their discussion of the wetland definition gives Lake Eyre as an example of one of the questionable wetlands since it is filled only a few times in 90 years. Yet, given that, it "may occasionally be significant for waterbirds and should count as a wetland." This type of area is a good example of a cyclical wetland (see Chapter 7). Such wetlands are common in arid regions of the world.

Another Australian wetland definition was developed by the Wetland Advisory Committee (1977). This definition has been adopted for inventorying wetlands in Western Australia:

> Wetlands are "areas of seasonally, intermittently, or permanently waterlogged soils or inundated land, whether natural or artificial, fresh or saline, e.g., waterlogged soils, ponds, billabongs, lakes, swamps, tidal flats, estuaries, rivers and their tributaries."

Wetlands can be identified by the presence of water or waterlogged soils that support vegetation typical of wet conditions and/or hydric soils, with the limits determined by dampness

* The Ramsar wetland classification system includes coastal lagoons, lakes, rivers, streams, and subterranean karst and cave hydrological systems (see Chapter 8).

conditions, characteristic vegetation, or hydric soils (Semeniuk Research Group, 1992). This wetland definition includes all waterbodies in addition to vegetated and nonvegetated periodically waterlogged lands.

In their wetland policy document, New South Wales Government (2010) included the following definition:

> Wetlands are areas of land that are wet by surface water or groundwater, or both, for long enough periods that the plants and animals in them are adapted to, and depend on, moist conditions for at least part of their lifecycle. They include areas that are inundated cyclically, intermittently or permanently with fresh, brackish or saline water, which is generally still or slow moving except in distributary channels such as tidal creeks which may have higher peak flows.

This definition clearly includes areas that are wet only during high precipitation cycles. The policy further emphasizes this point by the following statements:

> Many wetlands are ephemeral, that is, they are not always wet. As a result, the temporary absence of water will not necessarily be used to exclude particular areas of land from the definition of "wetland" under this policy. This issue is especially relevant for demarcating wetlands on floodplains, where wetland extent may vary according to the size and duration of the last flood, as well as local rainfall and the degree of groundwater connectivity. Ephemeral wetlands occur on many riverine systems where temporary flood retention leads to significant flood supported ecosystems. These areas are particularly susceptible to development as they often are difficult to define on ephemeral river and creek systems.

The document also clarifies that the intent is to include areas that hold water after major floods and not floodplains that drain freely after such events.

The State of Queensland used the following definition in conducting an inventory of its wetlands (Environmental Protection Agency, 2005):

> Wetlands are: Areas of permanent or periodic/intermittent inundation, with water that is static or flowing fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 m. To be a wetland the area must have one or more of the following attributes: i. at least periodically the land supports plants or animals that are adapted to and dependent on living in wet conditions for at least part of their life cycle, or ii. the substratum is predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers, or iii. the substratum is not soil and is saturated with water, or covered by water at some time.

This definition appears to have adapted the three indicators (attributes) of wetlands referenced in the Cowardin et al. (1979) definition. Wetlands extend to a depth of 19.7 ft (6 m) in marine waters; this is consistent with the Ramsar definition. Animals and plants can be used to identify wetlands. Wetland soils are anaerobic in the upper part, or if the substrate is not soil, then hydrology is used to determine the presence of wetland. The definition includes areas mapped as certain features (river, creek, swamp, lake, marsh, waterhole, wetland, billabong, pool, or spring), areas containing listed hydrophytes, saturated parts of the riparian zone, artificial wetlands (e.g., farm dams), and waterbodies not connected to rivers or flowing water (e.g., billabongs and rock pools). It excludes the "riparian zone above the saturation level" and floodplains that are intermittently covered by flowing water and lack hydrophytes and soil criteria (Environmental Protection Agency, 2005).

Brazil Wetland Definition

An estimated 20% of the land surface of Brazil, the fifth largest country in the world, contains wetlands, representing a wide diversity of types including one of the world's largest wetlands—the

Pantanal (Junk et al., 2011). In a potentially seminal paper on Brazilian wetlands, Junk et al. (2014) proposed the following definition:

> Wetlands are ecosystems at the interface between aquatic and terrestrial environments; they may be continental or coastal, natural or artificial, permanently or periodically inundated by shallow water or consist of waterlogged soils. Their waters may be fresh, or highly or mildly saline. Wetlands are home to specific plant and animal communities adapted to their hydrological dynamics.

They also recommend including dryland inclusions as part of the wetland for delineation purposes: "The definition of a wetland area should include, if present, internal permanently dry areas as these habitats are of fundamental importance to the maintenance of the functional integrity and biodiversity of the respective wetland." This is an interesting concept and one that is clearly important to biota, functions, and native peoples. This definition and its accompanying wetland classification system (see Chapter 8) are intended to represent the foundation for a national wetland conservation policy that would help educate others on the diversity of wetlands, their importance, and threats.

China Wetland Definition

Since the mid-1990s, China has been collecting more information about the country's wetlands. In *Mires of China*, the compilation of a 3-year survey, Kuiyi Zhao (1999) defined wetland as "a special natural complex with three interconnected and interconstrained properties: earth's surface perennially inundated by stagnant water or water-soaked soil, the growth of wetland and mire plants, and peat accumulation or soil with obvious gley horizon" (Zhao et al., 2010). China's State Forestry Administration developed national rules for wetland protection, which were adopted for implementation on March 28, 2013. The rules use a modified version of the Ramsar wetland definition:

> The perennial or seasonal areas of water, water and areas of marine water that the depth of which at low tide does not exceed six meters, including marshes, lake wetlands, river wetlands, coastal wetland and other natural wetlands and artificial wetlands that are habitat for key protected wildlife and wild plants.
>
> **Yanmei and Yue (2014)**

Interestingly, this definition conflicts with some provincial wetland definitions that designate only certain wet areas as "wetlands" listed for protection.

Kenya Wetland Definition

Kenya's National Wetland Standing Committee defined wetlands as "areas of land that are permanently, seasonally or occasionally waterlogged with fresh, saline, brackish or marine waters at a depth not exceeding six metres, including both natural and man-made areas that support characteristic biota" (Kiai and Mailu, 1998). This committee chose this definition over the Ramsar definition to emphasize biodiversity and the importance of wetlands to all biota as the original focus of the Ramsar Convention was on the conservation of wetlands with special attention to waterfowl given their migratory nature and dependence on wetlands across national borders.

New Zealand Wetland Definition

New Zealand's Resource Management Act of 1991 contains the following definition: "Wetland includes permanently or intermittently wet areas, shallow water, and land water margins that support a natural ecosystem of plants and animals that are adapted to wet conditions." This definition would need further clarification for field applications as questions about water depth for "shallow water" and what constitutes the waterward extend of the "land water margins" remain. In a study of hydrology of 10 key wetlands in the Wellington region, Thompson (2012) slightly modified the definition for ease of application: "Wetlands is a collective term for permanently or temporarily wet areas, shallow water and landwater margins. Wetlands may be fresh, brackish or saline, natural or artificial, and are characterised in their functional state by plants and animals that are adapted to living in wet and waterlogged conditions."

Republic of Korea Wetland Definition

In 2008, South Korea enacted the Wetland Conservation Act to promote conservation and wise management of wetlands in part to protect their biological diversity and protect them from damage. The act defines wetlands as "the area of which the surface is covered permanently or temporarily by freshwater, estuary water, or saltwater, and refers to inland wetlands and coastal wetlands." Inland wetlands consist of lakes, marshes, estuaries, and similar areas, while coastal wetlands are defined as "the area from the border where the water level touches the land at high tides to the border where the water level touches the land at low tides."

South Africa Wetland Definition

Like many countries who are signatories of the Convention on Wetlands (known as the Ramsar Convention), South Africa has adapted the Ramsar wetland definition as the foundation for a national wetland classification system (South African National Biodiversity Institute, 2009):

> WETLAND: an area of marsh, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed ten metres.

South Africa does have another wetland definition in the National Water Act, the country's only legislated wetland definition:

> Land which is transitional between terrestrial and aquatic systems, where the water table is usually at, or near the surface, or the land is periodically covered with shallow water and which land in normal circumstances supports, or would support, vegetation adapted to life in saturated soil.
>
> **South African National Biodiversity Institute (2009)**

This definition appears to be derived from the two U.S. federal wetland definitions: Cowardin et al. (1979) and the Clean Water Act regulatory definition (discussed later). Since the Ramsar definition is broader, wetlands regulated under the NWA represent only a subset of wetlands covered by the one designed for classification and inventory.

Uganda Wetland Definition

According to Uganda's 1995 national wetland policy, "a wetland is an area where plants and animals have become adapted to temporary or permanent flooding by saline, brackish or fresh water" (reported in Namirimu et al., 2013). Wetlands therefore include lakes and rivers, swamps, saturated land (bogs), and floodplains.

Zambia Wetland Definition

Perera (1982) generally described wetlands as "either an area of land in which periods of flooding and emergence of ground alternates or as areas that are permanently flooded with a water layer not exceeding several meters in depth." This definition contains about 20% of the country's land area.

Wetland Definition for Remote Sensing for Global Applications

The technology for mapping wetlands has changed dramatically since the 1970s. Today, advanced remote sensing techniques employ satellite imagery (multispectral and hyperspectral), data from other sensors (e.g., radar and LiDAR), and analytical techniques (e.g., object-based image analysis, data fusion, and Random Forests) (Tiner et al., 2015). After mapping wetlands for over 30 years, recognizing the inconsistencies in existing wetland inventories (however limited they may be globally), significant differences in the Ramsar definition and those used in North America, and considering the need for a global wetland standard for environmental modeling (e.g., carbon and methane cycling) and predicting the impact of climate change on wetlands, four researchers (Lang et al., 2015) proposed a wetland definition that was intended to be consistent with most of the definitions applied internationally to date:

> Wetlands are lands covered by shallow water or saturated at or near the surface for significant periods (permanently, seasonally, or intermittently) sufficient enough to support plants and animals dependent on or tolerant of prolonged inundation or saturation and to create hydric soils or substrates. Wetlands include: (1) habitats dominated by hydrophytic vegetation and hydric soils (e.g., marshes, swamps, bogs, and fens), (2) habitats characterized by aquatic vegetation and hydric substrates (i.e., aquatic beds and seaweed-covered rocky shores), (3) non-vegetated habitats subject to frequent or prolonged inundation or saturation (e.g., mudflats, rocky shores, beaches, and salinas), (4) coral reefs, and (5) the shallow water zone (<2.5 m at mean low water) of water bodies.

This definition excludes deeper waterbodies that are included in the Ramsar definition but includes coral reefs and submerged aquatic vegetation regardless of water depth; perhaps those deeper than 8.2 ft (2.5 m) should be considered "deepwater wetlands" or "benthic wetlands." While there should be widespread agreement on the central concept of a wetland, key questions remain on the upper and lower limits. For the upper boundary, what is the minimum frequency and duration of wetness necessary for an area to be defined as wetland? There is a hydrologic standard for U.S. wetlands (i.e., saturation within one foot of the soil surface during the growing season in most years; NRC, 1995), but how does this relate to "episodic wetlands" in arid regions (e.g., Australia)? For the lower limit, the question is: What is the maximum depth of a wetland for permanent waterbodies?

REGULATORY DEFINITIONS

Environmental laws have been passed to protect wetlands or to control certain activities that may jeopardize public resources or cause damage to public and private property. Legally, a wetland is whatever the law says it is. Regulatory definitions are largely grounded on scientific concepts but often include other considerations specifying lands of particular concern. For example, some definitions exclude certain areas due to tidal versus nontidal influence or interest in land use (e.g., agriculture in Alaska) or include deepwater areas (e.g., lakes and rivers) and other areas (e.g., banks and buffers) as wetlands for the purposes of regulating certain activities in these places.

Federal Clean Water Act Wetland Definition

The federal government regulates wetlands under two laws—the Rivers and Harbors Act and the Clean Water Act. The former is focused on navigable waters and deals more with disposal of dredged material and construction of potential hazards to navigation, while the latter is far more expansive in geographic scope and is mostly concerned with the deposition of fill in waters of the United States. Consequently, it is the Clean Water Act, particularly Section 404, that gets the most attention (for a review of federal wetland regulations, see Want, 1992; Dennison and Berry, 1993; Environmental Law Institute, 1993; Connolly et al., 2005; Johnson et al., 2007; Gardner, 2011; Strand and Rothschild, 2015).

The Section 404 program is jointly administered by the U.S. Army Corps of Engineers (Corps) and the U.S. EPA, with the Corps being largely responsible for issuing permits and the EPA providing program oversight. Wetlands are considered part of the waters of the United States since such waters ebb and flow over and/or through such lands and they are vital resources that help maintain the biological, chemical, and physical integrity of the nation's waters.

A 1975 U.S. district court decision (Natural Resources Defense Council v. Callaway; 392 F. Supp. 685, 5 ELR 20285) forced the Corps to expand its role in wetland regulation. To comply with the court's decision, the Corps proposed the following definition (40 Federal Register 31328, July 25, 1975):

> Wetlands are those land and water areas subject to regular inundation by tidal, riverine, or lacustrine flowage. Generally included are inland and coastal shallows, marshes, mudflats, estuaries, swamps, and similar areas in coastal and inland navigable waters.

After receiving significant public comment about this definition, the final regulatory definition was published (42 Federal Register 37125-26, 37128-29, July 19, 1977):

> Wetlands are "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 soils. Wetlands generally include swamps, marshes, bogs, and similar areas."

This definition requires that certain vegetation be present or capable of growing in the area to be classified as wetland. Such vegetation has been termed "hydrophytic vegetation" in manuals developed to apply this definition on the ground (Chapter 6). It is evident that this definition is limited to vegetated wetlands. It does not include mudflats, sandbars, beaches, rocky shores, and similar nonvegetated areas that may be viewed as wetlands from the scientific standpoint. It also does not include aquatic beds, such as water lily beds, since this vegetation is not growing on soil, but on a submerged substrate. The Corps does, however, recognize nonvegetated wetlands and aquatic beds as "special aquatic sites" and part of "other waters of the United States" for regulatory purposes, but they are not "regulated" or "jurisdictional" wetlands.*

The Section 404 definition includes the term "under normal circumstances" in regard to the presence of vegetation. This term was required to prevent people from seeking to remove a wetland area from regulation by simply eliminating the vegetation. Prior to 1989, the Corps' interpretation of normal circumstances was typically determined by the existing land use—determined on the basis of an area's characteristics and use at present and in the recent past (Offringa, 1986). If the area was farmed for some time, it was viewed as not supporting a prevalence of hydrophytic vegetation and was not wetland, even recognizing that "if left unattended for a sufficient period of time, [it would] revert to wetlands solely through the devices of nature" (Offringa, 1986). Consequently, farmed wetlands were excluded from the wetland definition. In 1989, the Corps and EPA adopted the concept of normal circumstances used in the Food Security Act (FSA), which defined normal circumstances in the absence of vegetation, on the basis of existing hydrology and the presence of hydric soils. This was a significant reinterpretation of the term, with major implications on the extent of regulated wetlands. Since 1989, farmed wetlands have been included in the scope of the federal regulatory definition.

While the regulatory definition of wetlands may include nearly all vegetated wetlands (except for aquatic beds), it is important to note that certain wetlands may not meet other criteria for designation as a regulated area (subject to federal jurisdiction). Perhaps the most significant of these are wetlands that are not directly connected to surface waters of the United States—so-called geographically isolated wetlands (GIWs; Tiner, 2003). A Supreme Court decision on January 2, 2001 (Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers [SWANCC]), put the focus on isolated wetlands by stating that the Corps exceeded their jurisdiction when regulating an isolated wetland solely by virtue of its use by migratory birds (see legal documents for

* The definition of "waters of the United States" is a matter of contention; since EPA and the Corps issued a final rule to define the term in May 2015, numerous lawsuits have challenged the regulation, and on December 9, 2015, a federal court blocked the rule's implementation nationwide (Copeland, 2015).

details; e.g., Cornell University Law School, Legal Information Institute, https://www.law.cornell.edu/supct/html/99-1178.ZS.html). The adjective "geographically" was added to the term "isolated" to emphasize that isolation was simply geographic (i.e., completely surrounded by nonhydric soil or nonwetland) and *not ecological or even hydrologic* as these wetlands may be connected to groundwater or intermittently connected to other wetlands and waters via surface water during extreme wet periods (Tiner, 2003; an entire issue of *Wetlands*—Volume 23 Issue 3, September 2003—was devoted to describing the functions and values of these types of wetlands). GIWs are a subset of wetlands that continue to be the source of much controversy regarding regulation and even whether the term itself should be used by scientists or not (Leibowitz, 2015; Mushet et al., 2015). The term has stimulated at least some interest in furthering research of these somewhat unique wetlands. In fact, a state-of-the-science report on connectivity of wetlands and streams by EPA (U.S. EPA, 2015) highlighted the need for more research on GIWs and cautious use of the term (e.g., not to imply lack of hydrologic or biological connectivity or functional significance). New research on their importance is being published (e.g., Marton et al., 2015; Rains et al., 2016) and more is expected in the immediate future. Since other criteria, besides is the area a wetland, come into play in determining the jurisdictional status of a wetland, consult the latest regulatory guidance from the U.S. Army Corps of Engineers and U.S. EPA for details.

Food Security Act Wetland Definition

In 1985, Congress passed the FSA (P.L. 99–198, 99 Stat. 1504) that contained provisions to discourage wetland drainage for crop production—the Swampbuster provision. This provision is quasi-regulatory in that the federal government would deny federal subsidies (agricultural loans, crop support payments, and other benefits) to farmers who drained wetlands to produce a commodity crop after December 23, 1985. For administering this provision, wetlands were defined as

> … areas that have a predominance of hydric soils and that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of hydrophytic vegetation typically adapted for life in saturated soil conditions, except lands in Alaska identified as having a high potential for agricultural development and a predominance of permafrost soils.
>
> **USDA Soil Conservation Service (1988, 1996)**

Wetlands are determined by three features (hydric soil, wetland hydrology, and hydrophytic vegetation), so it is a definition of vegetated wetlands. It contains a geographic exclusion for wetlands on certain agricultural lands in Alaska, since Congress did not want to prevent conversion of such wetlands (see Chapter 7 for discussion of this wetland type). This definition is actually the first wetland definition published in federal public law (16 U.S.C. Sect. 801 (a) (1)). It also has been used to define wetlands in the Emergency Wetlands Resources Act of 1986, but without the geographic exclusion for Alaska.

The FSA definition uses the term "normal circumstances" to refer to "soil and hydrologic conditions that are normally present, without regard to whether the vegetation has been removed" (USDA Natural Resources Conservation Service, 1996). Consequently, it includes many farmed wetlands where production was made possible or enhanced by manipulation and the area has not been abandoned. For purposes of the act, farmed wetlands are wetlands that were drained, dredged, filled, leveled, or otherwise manipulated before December 23, 1985, with the intent to grow an agricultural commodity crop but still retain some degree of wetland hydrology. In practice, farmed wetlands (if not a pothole, playa, or pocosin) must have a 50% chance of being inundated for at least 15 consecutive days during the growing season or 10% of the growing season, whichever is less. If the farmed area is a pothole, playa, or pocosin, it still qualifies as a farmed wetland if either flooded or ponded for at least 1 week (7 consecutive days) or saturated for at least 2 consecutive weeks during the growing season in most years. Thus, identifying a farmed wetland as one of the three specified types is critical to the determination of whether it is an FSA wetland. Wet pastures and hayfields also are included in the FSA definition provided they were used as such prior to December 23, 1985, and they are inundated for at least 1 week or saturated for at least 2 weeks during the growing season.

Excluded from the FSA definition are farmed wetlands that do not meet the hydrology requirements and "prior converted cropland." The latter category is a former or existing wetland that meets certain criteria: (1) has been used to produce a commodity crop at least once before December 23, 1985, (2) as of this date did not support woody plants, and (3) has the same hydrology as "farmed wetlands" mentioned in the preceding paragraph. Basically these are farmed wetlands that are not affected by FSA because they were cultivated prior to the establishment of the act. Wetlands cultivated or altered with the intent of growing a commodity crop after the act are considered "converted wetlands" for administrative purposes.

Selected State and Provincial Wetland Definitions

Since the 1960s, many states in the United States have recognized the significance of wetlands as natural resources and have passed laws to protect them from unwise development. More recently, neighboring Canadian provinces have enacted environmental protection laws or Clean Water Act laws to regulated wetland alterations. Given different interests and experiences, these wetland definitions are quite variable, but most have a common thread based on vegetation and hydrology. Soils may be referred to explicitly or may be inferred from the hydrologic conditions stated in most of the definitions. More recent state laws use the U.S. federal definition or something quite similar for inland wetlands (e.g., Maryland, New Jersey, and Wisconsin). Table 1.1 lists examples of state and provincial wetland definitions, including some of the early definitions and more recent ones. These governments may have multiple definitions; one for regulatory purposes and another for restoration and management or for promoting wetland conservation. For example, Arkansas includes various wetland types in its definition of state waters for its water and air pollution control regulations and a specific wetland definition for restoration and conservation planning (Environmental Law Institute, 2008; summarizes wetland programs for all 50 states). Prince Edward Island uses a slightly modified version of the Canadian national wetland definition for its wetland conservation policy and a more specific one for wetland regulation. Some states use a variation of the U.S. FWS (e.g., Hawaii), while many others have adopted the federal regulatory definition, with some modification for tidal wetlands (San Francisco Estuary Institute, 2009). The Association of State Wetland Managers maintains up-to-date information on state wetland programs, which may include wetland definitions used for law and policies in the United States (http://www.aswm.org/).

In drafting a wetland definition for proposed statewide wetland policy, the California State Water Resources Control Board (2013) recognized that some of the state's wetlands are not included in the federal regulatory definition and therefore proposed the following definition:

> An area is wetland if, under normal circumstances, (1) the area has continuous or recurrent saturation of the upper substrate caused by groundwater, or shallow surface water, or both; (2) the duration of such saturation is sufficient to cause anaerobic conditions in the upper substrate; and (3) the area either lacks vegetation or the vegetation is dominated by hydrophytes.

The main issue appears to be that the federal definition is one for vegetated wetlands and California has many nonvegetated wetlands (i.e., lacking vegetation due to "aridity and intolerable physiochemical or biotic conditions") such as tidal flats, playa, river bars, the shallow water zone of ponds, and wet bare areas within vegetated wetlands that they want to include in their dredge and fill regulations.

TABLE 1.1
Examples of Wetland Definitions Used by State and Provincial Regulatory Programs in the United States and Canada

State or Province	Definition
California	"Wetland shall be defined as land where the water table is at, near, or above the land surface long enough to promote the formation of hydric soils or to support the growth of hydrophytes, and shall also include those types of wetlands where vegetation is lacking and soil is poorly developed or absent as a result of frequent and drastic fluctuations of surface water levels, wave action, water flow, turbidity or high concentrations of salts or other substances in the substrate. Such wetlands can be recognized by the presence of surface water or saturated substrate at some time during each year and their location within, or adjacent to, vegetated wetlands or deep-water habitats." (State's regulatory definition for wetlands in the coastal zone according to the California Coastal Act; California Coastal Commission, 2011.)
Connecticut	"Wetlands are those areas which border on or lie beneath tidal waters, such as, but not limited to banks, bogs, salt marshes, swamps, meadows, flats, or other low lands subject to tidal action, including those areas now or formerly connected to tidal waters, and whose surface is at or below an elevation of 1 ft above local extreme high water." (State's tidal wetland definition in Tidal Wetlands Act; the definition also includes a list of indicator plants.)
Connecticut	"Wetlands mean land, including submerged land, which consists of any of the soil types designated as poorly drained, very poorly drained, alluvial, and floodplain by the National Cooperative Soils Survey, as may be amended from time to time, of the Soil Conservation Service of the United States Department of Agriculture." (State's inland wetland regulatory definition according to the Connecticut Inland Wetlands and Watercourse Act; it focuses on soil types.)
Florida	"*Wetlands* mean those areas that are inundated or saturated by surfacewater or groundwater at a frequency and a duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soils. Soils present in wetlands generally are classified as hydric or alluvial, or possess characteristics that are associated with reducing soils conditions. The prevalent vegetation in wetlands generally consists of facultative or obligate hydrophytic macrophytes that are typically adapted to areas having soil conditions described above. These species, due to morphological, physiological, or reproductive adaptations, have the ability to grow, reproduce, or persist in aquatic environments or anaerobic soil conditions. Florida wetlands generally include swamps, marshes, bayheads, bogs, cypress domes and strands, sloughs, wet prairies, riverine swamps and marshes, mangrove swamps, and other similar areas. Florida wetlands generally do not include longleaf or slash pine flatwoods with an understory dominated by saw palmetto." (Statewide definition according to Chapter 62–340, Florida Administrative Code [Wetland Delineation] and Florida Statute Title XXVIII [Natural Resources] Chapter 373 [Water Resources] includes tidal and nontidal wetlands but excludes certain plant communities.)
Georgia	"*Coastal marshlands* include [a]ny intertidal marshland area, mud flat, tidal water bottom, or salt marsh in the state of Georgia within the estuarine areas of the state." "Vegetated marshlands" are "areas upon which grow one, but not necessarily all, of the following: salt marsh grass (*Spartina alterniflora*), black needlerush (*Juncus roemerianus*), saltmeadow cordgrass (*Spartina patens*), big cordgrass (*Spartina cynosuroides*), saltgrass (*Distichlus spicata*), coast dropseed (*Sporobolus virginicus*), bigelow glasswort (*Salicornia bigelovii*), woody glasswort (*Salicornia virginica*), saltwort (*Batis maritima*), sea lavender (*Limonium nashii*), sea oxeye (*Borrichia frutescens*), silverling (*Baccharis halimifolia*), false willow (*Baccharis angustifolia*), and high-tide bush (*Iva Frutescens*)." "Estuarine areas" include "[a]ll tidally influenced waters, marshes, and marshlands lying within a tide elevation range from 5.6 feet above mean tide level and below." (State's wetland definition for Coastal Marshlands Protection Act; although not "wetland" this is the state's definition for regulating tidal marshes; the state's "freshwater wetlands" are defined using the federal regulatory definition and excludes coastal marshlands.)

(*Continued*)

TABLE 1.1 (*Continued*)
Examples of Wetland Definitions Used by State and Provincial Regulatory Programs in the United States and Canada

State or Province	Definition
Illinois	"*Wetland* means land that has a predominance of hydric soils (soils which are usually wet and where there is little or no free oxygen) and that is inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances does support, a prevalence of hydrophytic vegetation (plants typically found in wet habitats) typically adapted for life in saturated soil conditions. Areas which are restored or created as the result of mitigation or planned construction projects and which function as a wetland are included within this definition even when all three wetland parameters are not present." (State wetland definition for Interagency Wetland Policy Act of 1989).
Maryland	Tidal wetlands are "all state and private tidal wetlands, marshes, submerged aquatic vegetation, lands, and open water affected by the daily and periodic rise and fall of the tide within the Chesapeake Bay and its tributaries, the coastal bays adjacent to Maryland's coastal barrier islands, and the Atlantic Ocean to a distance of 3 m offshore of the low water mark." (State's tidal wetland definition according to the Tidal Wetlands Act; it includes deepwater areas, for nontidal wetlands.)
	"*Nontidal wetland* is an area meeting the following conditions: (a) …an area that is inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances does support, a prevalent of vegetation typically adapted for life in saturated soil conditions, commonly known as hydrophytic vegetation; (b) is determined according to the Federal Manual; (c) does not include tidal wetlands regulated under Natural Resources Article, Title 9, Annotated Code of Maryland." (State regulatory definition according to the Nontidal Wetlands Protection Act; original reference was to the interagency manual, but now use the Corps manual and regional supplements).
Massachusetts	"Salt Marsh means a coastal wetland that extends landward up to the highest high tide line, that is, the highest spring tide of the year, and is characterized by plants that are well adapted or prefer living in saline soils. Dominant plants within salt marshes are salt meadow cord grass (*Spartina patens*) and/or salt marsh cord grass (*Spartina alterniflora*). A salt marsh may contain tidal creeks, ditches, and pools." (State's coastal wetland definition; it was published in the first state wetland law in the nation in 1962—Jones Act; updated definition of "salt marsh" for Wetlands Protection Act: "a coastal wetland that extends landward up to the highest high tide line, that is, the highest spring tide of the year, and is characterized by plants that are well adapted to or prefer living in, saline soils. Dominant plants within salt marshes typically include salt meadow cord grass (*Spartina patens*) and/or salt marsh cord grass (*Spartina alterniflora*), but may also include, without limitation, spike grass (*Distichlis spicata*), high-tide bush (*Iva frutescens*), black grass (*Juncus gerardii*), and common reedgrass (*Phragmites*). A salt marsh may contain tidal creeks, ditches and pools.")
Massachusetts	"Bordering Vegetated Wetlands are freshwater wetlands which border on creeks, rivers, streams, ponds and lakes. The types of freshwater wetlands are wet meadows, marshes, swamps and bogs. Bordering Vegetated Wetlands are areas where the soils are saturated and/or inundated such that they support a predominance of wetland indicator plants. The ground and surface water regime and the vegetational community which occur in each type of freshwater wetland are specified in [the Act]." "The boundary of Bordering Vegetated Wetlands is the line within which 50% or more of the vegetational community consists of wetland indicator plants and saturated or inundated conditions exist." (State's inland wetland definition according to the Wetlands Protection Act; it only pertains to wetlands that border waterbodies; geographically isolated wetlands may be classified as "isolated land subject to flooding" if they meet certain requirements [e.g., closed basin that annually stores at least ¼ acre-foot of water to an average depth of 6 in.].)

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TABLE 1.1 (*Continued*)
Examples of Wetland Definitions Used by State and Provincial Regulatory Programs in the United States and Canada

State or Province	Definition
Minnesota	"*Public waters wetlands* means all types 3, 4, and 5 wetlands, as defined in United States Fish and Wildlife Service Circular No. 39 (1971 edition), not included within the definition of public waters, that are ten or more acres in size in unincorporated areas or 2–1/2 or more acres in incorporated areas." (State definition under Public Waters Work Permit Program for regulating subset of wetlands that are considered public waters; types 3, 4, and 5 are inland shallow fresh marshes, inland deep fresh marshes, and inland open freshwater, respectively; boundary is determined by the ordinary high water level—"an elevation delineating the highest water level that has been maintained for a sufficient period of time to leave evidence upon the landscape, commonly the point where the natural vegetation changes from predominantly aquatic to predominantly terrestrial" [Minnesota Board of Water and Soil Conservation, 2003].)
Minnesota	"*Wetlands* mean lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this definition, wetlands must have the following three attributes: (1) have a predominance of hydric soils; (2) be inundated or saturated by surface water or ground water at a frequency and duration sufficient to support a prevalence of hydrophytic vegetation typically adapted for life in saturated soil conditions; and (3) under normal circumstances support a prevalence of hydrophytic vegetation." (State definition for the Wetland Conservation Act of 1991; intended to cover all wetlands not considered public water wetlands; adapted from U.S. Fish and Wildlife Service and federal regulatory definitions.)
New Brunswick	"Land that has the water table at, near, or above the land's surface, or which is saturated, for a long enough period to promote wetland or aquatic processes as indicated by hydric soils, hydrophytic vegetation, and various kinds of biological activities adapted to the wet environment." (Provincial definition in its wetland conservation policy document; definition appears derived from various North American definitions [New Brunswick, 2002].)
New Jersey	Coastal wetlands are "any bank, marsh, swamp, meadow, flat, or other lowland subject to tidal action in the Delaware Bay and Delaware River, Raritan Bay, Sandy Hook Bay, Shrewsbury River, including Navesink River, Shark River, and the coastal inland waterways extending southerly from Manasquan Inlet to Cape May Harbor, or any inlet, estuary or those areas now or formerly connected to tidal waters whose surface is at or below an elevation of 1 ft above local extreme high water, and upon which may grow or is capable of growing some, but not necessarily all, of the following:" (19 plants listed). Coastal wetlands exclude "any land or real property subject to the jurisdiction of the Hackensack Meadowlands Development Commission…" (State's tidal wetland definition according to the Wetlands Act of 1970; it contains a geographic exclusion for areas already under control of another state agency.)
New Jersey	"Freshwater wetland means an area that is inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances does support, a prevalence of vegetation typically adapted for life in saturated soil conditions, commonly known as hydrophytic vegetation; provided, however, that the department, in designating a wetland, shall use the three-parameter approach … developed by the U.S. Environmental Protection Agency, and any subsequent amendments thereto…" (State's inland or freshwater wetland definition according to the Freshwater Wetlands Protection Act.)

(*Continued*)

TABLE 1.1 (*Continued*)
Examples of Wetland Definitions Used by State and Provincial Regulatory Programs in the United States and Canada

State or Province	Definition
New York	"Freshwater wetlands means lands and waters of the state as shown on the freshwater wetlands map which contain any or all of the following: (a) lands and submerged lands commonly called marshes, swamps, sloughs, bogs, and flats supporting aquatic or semi-aquatic vegetation of the following types: (lists indicator trees, shrubs, herbs, and aquatic species); (b) lands and submerged lands containing remnants of any vegetation that is not aquatic or semi-aquatic that has died because of wet conditions over a sufficiently long period … provided further that such conditions can be expected to persist indefinitely, barring human intervention; (c) lands and waters substantially enclosed by aquatic or semi-aquatic vegetation … the regulation of which is necessary to protect and preserve the aquatic and semi-aquatic vegetation; and (d) the waters overlying the areas set forth in (a) and (b) and the lands underlying (c)." (State's inland wetland definition according to the Freshwater Wetlands Act; the definition includes lists of indicator species for each wetland type; the state regulates *mapped* wetlands—generally wetlands 12.4 ac. or larger, or if smaller are deemed of unusual local importance or occur within the Adirondack Park.)
Nova Scotia	"An area commonly referred to as marsh, swamp, fen or bog that either periodically or permanently has a water table at, near or above the land's surface or that is saturated with water. Such an area sustains aquatic processes as indicated by the presence of poorly drained soils, hydrophytic vegetation and biological activities adapted to wet conditions." (Provincial definition for its Wetland Conservation Policy, essentially the same as that in the province's Environmental Act; the document further defines different wetland types ["classes"]: bog, coastal saline pond, fen, marsh [deep, shallow, shoreline, and salt], swamp, and vernal pool [Nova Scotia, 2011].)
Prince Edward Island	*Wetland* is defined as (i) an area which contains hydric soil, aquatic or water-tolerant vegetation, and may or may not contain water, and includes any water therein and everything up to and including the wetland boundary, and (ii) without limiting the generality of the foregoing, includes any area identified in the Prince Edward Island Wetland Inventory as open water, deep marsh, shallow marsh, salt marsh, seasonally flooded flats, brackish marsh, a shrub swamp, a wooded swamp, a bog or a meadow." (Definition for Watercourse and Wetland Protection Regulations under the province's Environmental Protection Act; the regulations also include a 15 m buffer around wetlands in the regulated zone and define how wetland boundary is determined: "where the vegetation in a wetland changes from aquatic or water-tolerant vegetation to terrestrial vegetation or water-intolerant vegetation" [Prince Edward Island, 2012].)
Rhode Island	"Coastal wetlands include salt marshes and freshwater or brackish wetlands contiguous to salt marshes. Areas of open water within coastal wetlands are considered a part of the wetland. Salt marshes are areas regularly inundated by salt water through either natural or artificial water courses and where one or more of the following species predominate: (eight plants listed). Contiguous and associated freshwater or brackish marshes are those where one or more of the following species predominate: (nine plants listed)." (State's coastal wetland definition through the Coastal Resources Management Council, which manages the state's coastal resources; the definition includes lists of indicator species; the first part of the definition was slightly modified by January 2015: "Coastal wetlands include salt marshes and freshwater or brackish wetlands contiguous to salt marshes or physiographical features. Areas of open water within coastal wetlands are considered a part of the wetland. In addition, coastal wetlands also include freshwater and/or brackish wetlands that are directly associated with non-tidal coastal ponds and freshwater or brackish wetlands that occur on a barrier beach or are separated from tidal waters by a barrier beach." Each type listed within this definition is further defined: low salt marsh, high salt marsh, contiguous brackish wetlands, and contiguous freshwater wetlands, with a short list of indicator plants for all the salt and brackish types.)

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TABLE 1.1 (*Continued*)
Examples of Wetland Definitions Used by State and Provincial Regulatory Programs in the United States and Canada

State or Province	Definition
Rhode Island	Freshwater wetlands are defined to include, “but not be limited to marshes, swamps, bogs, ponds, river and stream flood plains and banks; areas subject to flooding or storm flowage; emergent and submergent plant communities in any body of fresh water including rivers and streams and that area of land within fifty feet (50′) of the edge of any bog, marsh, swamp, or pond.” (State’s inland wetland definition from the Rhode Island Freshwater Wetlands Act; various wetland types are further defined based on hydrology and indicator plants; definition was refined by rules and regulations published in 1998, “Freshwater Wetland means the following: A. Bog, flood plain, pond, marsh, river bank, swamp, river, area of land within fifty feet (50′), area(s) subject to flooding, area(s) subject to storm flowage, floodway, flowing body of water, stream, intermittent stream, perimeter wetland, submergent and emergent plant communities, special aquatic sites, and shrub and forested wetland; B. Those areas that are inundated or saturated by surface or groundwater 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; and C. Any or all wetlands created as part of, or the result of, any activity permitted or directed by the Department after July 16, 1971 including, but not limited to: restored wetlands; value replacement wetlands created to compensate for wetland loss such as flood plain excavations; biofiltration areas; and any wetlands created, altered or modified after July 16, 1971.”)
Vermont	“Wetlands means those areas of the state that are inundated by surface or groundwater with a frequency sufficient to support significant vegetation or aquatic life that depend on saturated or seasonally saturated soil conditions for growth and reproduction. Such areas include but are not limited to marshes, swamps, sloughs, potholes, fens, river and lake overflows, mud flats, bogs and ponds, but excluding such areas as grow food or crops in connection with farming activities.” (State’s wetland definition under Vermont Wetland Rules.)
Wisconsin	“An area where water is at, near, or above the land surface long enough to be capable of supporting aquatic or hydrophytic vegetation and which has soils indicative of wet conditions.” (State’s wetland definition for Department of Natural Resources permit.)

Note: Some states use the federal regulatory definition for inland wetland programs (e.g., Maryland, Oregon, and Pennsylvania) or for other programs (e.g., water quality certification).

State wetland definitions also may include areas beyond ecological wetlands that the state considers important for maintaining the functions to be protected by state law. For example, both Massachusetts and Rhode Island include riverbanks and the 100-year floodplain in their definitions. Rhode Island also includes a 50-foot buffer in its designated wetland (Rhode Island Department of Environmental Management, 1994). New Jersey’s Pinelands Commission (1980) definition of wetlands includes submerged lands (lakes, ponds, rivers, and streams).

The interpretation of the definitions may lead to significant differences, even though the definitions appear similar. For example, Wisconsin’s definition is quite similar to the federal regulatory definition. The state clearly points out that the definition closely follows the 1989 manual’s concept but recognizes that there may be situations where differences occur (1) in “somewhat poorly drained” soils capable of supporting hydrophytic vegetation and (2) where hydrology is altered but the site is still capable of supporting wetland plants (Wisconsin Coastal Management Program, 1995). These sites may be considered regulated wetlands by the state.

FIELD APPLICATION OF WETLAND DEFINITIONS

Applying any of the wetland definitions on the ground requires knowledge of several disciplines (especially botany, soil science, and hydrology, with an emphasis on the first two). Consequently, plant, soil, and hydrology indicators must be established and the more reliable ones used to identify wetlands. For general research prior to the 1980s, scientific definitions were interpreted largely by biologists, applying their knowledge of ecology (plant–soil–hydrology relationships) and geomorphology (e.g., landscape position and landform). In contrast, federal agencies have developed manuals for interpreting the regulatory definition in an attempt to achieve consistency and repeatability in application among regulators and the regulated public. Since these definitions serve to identify lands subject to government regulations, precise and accurate delineations need to be performed in the name of good government. The manuals use certain biologic or physical features, namely, plants, soils, and signs of hydrology, to establish criteria for verifying the presence of potentially regulated wetlands (see Chapter 6 for discussion of methods). It is important to recognize that a criterion can be validated by any evidence that has bearing, so, for example, a hydric soil property (such as undrained organic soil) could be used to verify wetland hydrology (National Research Council, 1995).

A nationally applied wetland definition needs to consider three levels for interpretation—criteria, indicators, and regional variation (National Research Council, 1995); the same holds true internationally but on a much broader scale. Wetland identification criteria can include biological criteria (organisms) and physical criteria (wet substrates and soils, hydrology) as well as policy considerations for regulatory definitions. Biological indicators are certain plants and animals found in water or wetlands. Wet substrate/soil indicators are hydric soil properties plus submerged substrates and periodically flooded rocks or bedrock. Hydrology indicators can be any of the indicators mentioned earlier as well as indirect and direct evidence of flooding or waterlogging. Regional variation can be addressed by listing typical plants and/or plant communities and soil types, for example, used to indicate or validate a criterion. The Corps' regional supplements attempt to do this for the United States (see Chapter 6 for more details). Beyond what is or is not a wetland from a scientific perspective, regulatory considerations can include interpretations of what constitutes a significant "resource area" based on matters of size, location in the watershed, wetland type, and regional abundance of wetlands, for example. These policy factors may be explicit or implicit.

The key to accurate identification of wetlands is to have a well-conceived, science-based definition and fairly explicit guidance on the appropriate use of various wetland indicators to verify the presence of wetlands on the ground. Such guidance should be able to handle the majority of wetlands without difficulty and provide a list of known exceptions with specific instructions on how to evaluate them. This type of approach would promote accurate, precise, and consistent wetland identification and delineation.* Once identified as wetland, regulators could then superimpose their value system to determine which wetlands should be regulated and to what degree. The distinction between ecological wetlands and the subset that warrant regulatory considerations should be made clear by the regulatory community.

WETLAND CONCEPTS FOR IDENTIFICATION AND DELINEATION

Wetland identification and delineation require an understanding of certain fundamental concepts, since this work involves more than simply following guidance in a government manual. The use of best professional judgment is commonly needed to interpret key provisions, especially for

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* In the United States, the federal government has come a long way in pursuit of these objectives with publication of the Corps regional supplements.

problematic situations. Wetland delineators therefore need to be familiar with plant–soil–water relationships and general wetland ecology; wetland ecology textbooks represent an excellent starting point—technical ones such as Mitsch and Gosselink (2015), Batzer and Shartiz (2014), Tiner (2013), and Keddy (2010) or more general guidebooks like Tiner (2005). There is universal recognition that the forcing function of wetlands is hydrology, that is, an abundance of water sufficient to exert a controlling influence on plant or animal life or soil development (National Research Council, 1995). Yet to really understand this dominant influence, there are many issues pertaining to wetland hydrology that are significant for wetland identification and delineation. Some issues have been at the root of the controversy over what habitats actually constitute wetlands, at least from the regulatory point of view. Ecological concepts relating to wetland formation and development also have influenced today's concept of wetland.

Seven key questions reveal the underlying concepts upon which wetland definitions are based or expose some shortcomings of current definitions*:

1. How wet is a wetland?
2. What is the significance of "growing season" in defining wetland hydrology?
3. Are all wetlands at least periodically anaerobic environments?
4. Are wetlands simply ecotones between land and water?
5. Do wetlands include all riparian habitats?
6. Do wetlands eventually become drylands in a natural order of terrestrialization?
7. Are some wetlands ephemeral features on the landscape and cyclical in occurrence?

There may be other relevant questions, but these seven should include the most important ones. Most of these questions relate to hydrology, which is the master variable of wetlands and a topic that has received the least study in terms of wetlands. Only recently has more attention been given to this crucial topic. Please note that Chapter 2 describes wetland hydrology in more detail along with discussion of factors influencing wetland formation. In addressing the questions mentioned earlier, the U.S. experiences will be emphasized since this country has probably dedicated more attention and more resources to the topics than other countries largely due to the regulatory interests in wetlands.

The following discussion of these questions is not intended to be an exhaustive treatise but should be sufficient to help readers better understand the current concept of wetland and some key issues underlying much of the current debate that has surrounded the definition of wetland and its application on the ground. Noticeably absent from this list is a question dealing with wetland functions, although some discussion of this is provided in the response to question No. 2. Some scientists have suggested that defining wetlands by functions would help solve the debate raised by question No. 1. Yet this position appears naive as a significance test would still be required, for example, the minimum frequency, duration, and intensity (level) of the performance of a given function, especially since many valued "wetland" functions, such as flood storage, shoreline stabilization, and groundwater recharge, are not unique to wetlands. Once wetlands are defined, other significant questions are worth considering in the regulatory context (e.g., regarding wetland evaluation): Is wetter better? Should created wetlands be regulated the same as "natural" wetlands? Are restored or created wetlands acceptable functional replacements for existing wetlands? But they are not the subject of this book (see Environmental Defense Fund and World Wildlife Fund, 1992; Leidy et al., 1992; Zedler and Lindig-Cisneros, 2000; Edwards and Proffitt, 2003; Falk et al., 2006; Ballantine and Schneider, 2009; Moreno-Mateos et al., 2012, for further discussion).

* Although the text from the original version of this book also listed seven questions, I removed the one dealing with common types of wetland hydrology as it is more fully discussed in a new chapter on wetland formation and hydrology (Chapter 2) and in the wetland classification chapter (Chapter 8); I replaced it with a question about riparian habitat.

How Wet Is a Wetland?

This is the definitive question for wetland identification, and if the answer was simple, much academic and political debate could be eliminated. The name "wetland" implies land having significant wetness. Flooding virtually eliminates gas exchange between the soil and the atmosphere, and the supply of dissolved oxygen in the soil is soon exhausted by soil microbial respiration in only hours or days, causing the soil to become anaerobic (Evans and Scott, 1955; Takai et al., 1956; Turner and Patrick, 1968; Monhanty and Patnaik, 1975; Jackson and Drew, 1984; Wakeley et al., 1996). Significant wetness, as one can see in reviewing the wetland definitions presented earlier, has traditionally been defined as wet enough to create certain plant communities (to support hydrophytes or hydrophytic vegetation) and/or hydric soils. Yet the minimum hydrology required to support such vegetation and to form such soils has not been the object of scientific study; the issue tends to be a regulatory matter for determining if a wetland subject to altered hydrology is still wet enough to be a jurisdictional wetland or where on the natural soil moisture gradient should one draw the boundary between wetland and dryland. Thus, one has to examine information gleaned from existing studies of vegetation and soils to develop a best approximation. This is a challenging assignment due to the diversity of wetland types and associated environmental conditions.

Hydrology is by its very nature dynamic, varying annually, seasonally, and daily from wetland to wetland (no two are exactly alike) and from region to region (see Chapter 2). Consequently, hydrologic assessments require long-term studies to document the fluctuations in surface water levels and in the position of the water table. While considerable scientific study has been devoted to assessing the hydrology of rivers and streams and forests, relatively few studies have examined the hydrology of wetlands. Scientific research has not focused on examining these long-term hydrologic relationships in wetlands, especially along their upper limits, for several reasons: (1) the recent interest in this topic is due to regulatory needs, (2) wetland identification by plants and/or soils was widely accepted as a practical approach and using specific hydrologic conditions to determine wetland limits is a relatively new approach, and (3) the long-term commitment of resources (dollars and time) required to undertake such a task (Tiner, 1993a). Groundwater flow systems are particularly difficult and expensive to monitor due to the need for instrumented well fields and the presence of often discontinuous confining beds (Woo and Winter, 1993).

The lack of specific hydrologic data to establish the limits of wetland coupled with the high variability in hydrology among wetlands is undoubtedly the primary reason why definitions of "wetland" avoid specificity and merely state that the area is wet enough to support hydrophytic vegetation and/or to form hydric soils. Reliance on certain plants and soils as indicators of wetland has been and will undoubtedly continue to be the main criteria used to identify and delineate wetlands (Chapter 6), since they are more readily observed than the presence of water at a given site, especially during a single site visit. The NRC's wetland definition emphasizes this point: "Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. These features will be present except where specific physiochemical, biotic, or anthropogenic factors have removed them or prevented their development" (NRC, 1995). In fact, the presence of water at a given point in time does little by itself to indicate the presence of wetland, given the temporal nature of water in most wetlands and uplands. Observation of water in the soil on a given day does not give any indication of how long it has been there, how long it will persist, and how frequently such event occurs. Plants and soil properties at a site are, in large part, the expressions or manifestations of site wetness and are the indicators of how wet the site really is, provided it has not been drained. For example, when water is observed in conjunction with floating-leaved aquatic plants (e.g., *Nuphar*, *Nymphaea*, and *Brasenia*), a well-reasoned interpretation would be that the area is permanently flooded or nearly so. However, if a cornfield is flooded, the interpretation is likely to be that the presence of water is temporary. The vegetation assists with the interpretation of the duration and frequency of wetness.

Vegetation itself has a significant effect on the hydrology of a site. For example, the USDA Forest Service's loblolly pine management guide cautions that "a mature, well-stocked stand of trees often appear to be better drained than they really are. These sites may become exceedingly wet after transpiration losses are eliminated by harvesting the trees. As the new stand develops, moisture loss through transpiration will supplement drainage through the soil, drying the site" (McKee, 1989). This document correctly points out that increased transpiration from tree cover often has a significant effect on the local water table and seemingly dry areas are wetter than their superficial appearance. Measurements of the water table in forests may not reflect site wetness without tree cover, for example, marginally wet flatwoods are wetter than they appear. The rise in water tables after tree harvest due to decreased evapotranspiration has been well documented (e.g., Verry, 1986; Dubé et al., 1995; Miller, 2001; Adamus, 2014). Also the process of paludification where the ability of peat moss to absorb water, migrate upslope, and transform nonwetlands to blanket bogs is another example of the influence of plants on hydrology (Chapter 2).

Although an interesting theoretical topic, the real need to establish a lower threshold for wetland hydrology is a practical one—for regulatory determinations. In evaluating altered sites where drainage has lowered the seasonal high water table of wetlands, wetland regulators and the regulated public need a threshold to determine which wetlands are now effectively drained and which ones are not. Yet, given the paucity of long-term hydrologic studies for the variety of wetland types across the country, it must be recognized that only an approximation of the minimum threshold for wetland hydrology can be established. And while it may be practical and necessary for assessing the status of hydrologically disturbed sites for regulatory purposes, it must be recognized that some unaltered natural wetlands may not satisfy this condition for reasons yet to be determined. Consequently, caution should be exercised when applying such threshold to unaltered wetlands. The Corps' "Technical Standard for Water-Table Monitoring of Potential Wetland Sites" (2005, p. 2) emphasizes this point: "This standard should not be used to overrule a wetland determination based on indicators of hydrophytic vegetation, hydric soil, and wetland hydrology on sites that are not significantly disturbed or problematic. Wetland indicators reflect natural processes that occur in wetlands and generally provide the best evidence that functioning wetlands are present on a site. The actual hydrologic regime required to produce and maintain a wetland may vary locally and regionally due to climate, landforms, geology, soils, and plant and animal adaptations. Therefore, any wetland hydrologic standard is necessarily an approximation and should be used only when an indicator-based wetland determination is not possible or would give misleading results."

In defining wetland hydrology, the four main factors to consider include (1) duration of wetness, (2) frequency of wetness, (3) depth of saturation, and (4) timing or seasonality of wetness. These four factors working together influence plant communities and soil formation as well as animal life and wetland functions.

Flooding or Waterlogging Duration

Many plants are intolerant of flooding and their seedlings perish after only hours of inundation (Kozlowski, 1984). The rate of oxygen depletion depends on several factors, including soil temperature, organic matter content, and chemical oxygen demand from ferrous iron and other reduced elements (Gambrell and Patrick, 1978). Flooding a soil for a day has been shown to create anaerobic conditions under certain situations (Turner and Patrick, 1968; as reported by Mitsch and Gosselink, 1993), and if it occurs during a period of active plant growth, such flooding can have a limiting effect under some circumstances. Plant morphological responses to flooding and saturation are important plant adaptations (see Chapter 3) and can develop in a relatively short period of time. For example, Gill (1975) observed formation of adventitious roots in experimentally flooded alders just 2–5 days after budbreak. Topa and McLeod (1986b) noted that after 30 days of anaerobic conditions, there was an abundance of adventitious roots and hypertrophied lenticels in wet-site loblolly and pond pine seedlings. In another paper, they reported that "only 15 days of anaerobic conditions were necessary to increase internal root porosities of loblolly and pond pine seedlings"; this is evidence of aerenchyma tissue, an important adaptation for life in waterlogged soils (Topa and McLeod, 1986a). McKevlin et al. (1987) also found that after 3 weeks of flooding, loblolly pine seedlings developed hypertrophied lenticels and stems. After reviewing the scientific literature, the NRC (1995) concluded that frequent flooding or waterlogging (saturation) for 14 consecutive days was sufficient to create a wetland environment.

Frequency of Prolonged Wetness

In much of the coterminous United States, especially east of the Mississippi Valley, precipitation is in excess of evaporation, so water is readily available throughout the year in most years. This has created favorable conditions for wetland formation, and as a result, most of the wetlands in the lower 48 states are located here. Precipitation patterns in this region are more or less predictable, recognizing seasonal and annual variations, so considering wetland hydrology in terms of an "average year" or conditions that prevail in most years has some merit and utility. Consequently, extended wetness occurring in most years (roughly every other year on average) has been the standard for wetland delineation in the United States following government manuals (Environmental Laboratory, 1987; Sipple, 1988; Federal Interagency Committee for Wetland Delineation, 1989) including the regional supplements to the Corps manual.

Precipitation patterns are much different in arid and semiarid regions, being characterized by annual water deficits and by frequent long-term droughts. "Average" wetness conditions are simply mathematical calculations with no ecological meaning in evaluating wetland hydrology for these regions. During wet periods in the normal hydrologic cycle, wetlands may form in normally dry or moist depressions on the landscape. These ephemeral, cyclical wetlands are not addressed in the current U.S. federal regulatory wetland definition. In studying soils in semiarid Australia, Coventry and Williams (1984) found that hydromorphic properties may develop in soils saturated for less than 5 weeks at a frequency of once every 3 years. Perhaps conditions that prevail more than 33 out of 100 years should be the metric for assessing wetland hydrology in dry climates. Interestingly, the Australian concept of wetland also includes cyclical wetlands that may be flooded by episodic events once every 100 years because of their importance to waterbirds (Paijmans et al., 1985). Is a moist soil in the desert wet enough to be a wetland? The ecological significance of cyclical wetlands in the United States needs further evaluation (see discussion on cyclical wetlands at the end of this chapter). Also, moist riparian habitats along rivers and streams in the arid West also are not considered wetland because they lack the required frequency and duration of wet conditions.

Critical Depth of Saturation

Saturation in the root zone is fundamental for defining wetland hydrology. The bulk of the roots in wetland plants is generally restricted to the upper, partly aerated zone of the soil (Costello, 1936; Boggie, 1972; Whigham and Simpson, 1978; Montague and Day, 1980; Lieffers and Rothwell, 1987; Sjors, 1991). Although there are reports of rooting to 2 ft (60 cm) or more in some wetland species, the majority of the roots tend to occur within 1 ft (30 cm) of the surface (Day and Dabel, 1978; Powell and Day, 1991; NRC, 1995). Rice, the most widely cultivated wetland species in the world, has an extensive root system of hundreds of adventitious roots and thousands of lateral roots and most of these occur within the top foot (30 cm) of soil (Morita, 1993). In studying root distribution in wet meadows of the Nebraska Sandhills, Moore and Rhoades (1966) found that one-half to two-thirds of the roots were located within the upper 2 in. (5 cm) of soil, although some roots went as deep as 4 ft. After reviewing the literature and combining this with his personal observations, Sipple (1992) concluded that most of the roots in wetland herbs occurred within the upper 6 in. (15 cm) and in woody plants within the upper 6–18 in. (15–46 cm).

Timing of Wetness

Excessive wetness during the growing season is limiting to most plants. Most plants cannot tolerate a couple of weeks of flooding during the height of the growing season. Certain stages of plants (e.g., seedlings) are more susceptible than others to early season wetness (Chapter 3). While plant growth is inhibited by prolonged waterlogging or flooding during the growing season, similar conditions during the so-called nongrowing season also may adversely affect plants. Certain plants may have a competitive advantage for life in wetlands if they can continue root growth, germinate, or initiate shoot growth prior to the growing season for other plants (see discussion on growing season later in this chapter).

Wetland Hydrology Defined

In their wetland characterization report, the NRC (1995) concluded that "wetland hydrology should be considered to be saturation within 1 ft of the soil surface for 2 weeks or more during the growing season in most years (about every other year on average)." The upper foot contains most of the plant roots that would be adversely affected by anaerobic conditions resulting from prolonged saturation. The NRC acknowledged that there may be regional variations due to climate, vegetation, soil, and geologic differences but found that no such data existed at the time of their review. Until information to the contrary is produced, this threshold should be considered the minimum time necessary to create conditions that support the growth of hydrophytic vegetation and sufficient to define wetlands hydrologically.

The definition of wetland hydrology once used for regulations and federal wetland policies seems to have fallen short of the technical standard defined by the NRC. For example, in identifying wetlands subject to the Federal Clean Water Act, the U.S. Army Corps of Engineers initially used a period between 5% and 12.5% of the growing season (in most years) as the standard according to their wetland delineation manual (Environmental Laboratory, 1987) and a March 6, 1992, guidance memorandum (Williams, 1992), although their wetland delineation training materials referred to 5% as the wetland hydrology threshold. This caused much confusion in establishing a minimum threshold for consistent application across the country. In addition, there was considerable discretion by the Corps districts for interpreting the Corps manual, especially for defining growing season (see section on growing season below), which led to significant inconsistencies. In applying the Swampbuster provision of the FSA of 1985 (and amendments), the National Resources Conservation Service required that farmed wetlands be flooded for at least 2 consecutive weeks during the growing season or 10% of the growing season in most years, whichever is less unless it is a pothole, playa, or pocosin that is inundated for at least 1 week or saturated for 2 weeks or more during the growing season (USDA NRCS, 1996). Both of these definitions of wetland hydrology were developed before the NRC reached its conclusions and were established presumably with an intent to have federal regulations and policies cover what these agencies believed to be "significant" wetlands for their respective programs. Subsequently, the agencies revised their guidelines in response to NRC's conclusions and recommendations (e.g., Corps regional supplements; see Chapter 6).

What Is the Significance of "Growing Season" for Defining Wetland Hydrology?

Extended flooding or prolonged saturation during the *growing season* exerts considerable stress on plants. Many species cannot tolerate even a few days of flooding during the growing season (Chapter 3). Given this limiting effect on plant activity, most wetland definitions emphasize wetness during the growing season, yet wetness during the so-called "nongrowing" season may have a beneficial effect on some plants. The definition of growing season has become critically important in setting the minimum threshold for wetland hydrology, especially for regulatory purposes. Knowing the beginning and end of the growing season and whether a site is wet during the growing season is important for wetland determinations, especially for sites with altered hydrology that often require hydrologic monitoring (e.g., U.S. Army Corps of Engineers, 2012).

Growing season has many definitions. In its common usage, it is an agricultural term referring to the period for growing cultivated crops—for germination (shoot emergence) of planted annual crops. Traditionally, the frost-free period has been used to define this growing season since it defines a period of no risk of crop damage due to killing frosts. It has little relevance to native plants as many are already growing well before this period.

Significant changes have occurred in the government's interpretation of "growing season" as it relates to wetland hydrology since the first edition of this book was published. For historic perspective, the following is a review of the former approaches and the rationale I provided in the first edition to help advance a new concept. At the end of this section, the current interpretation of growing season as it is applied in 2016 for jurisdictional wetland determinations in the United States will be presented. The use of various approaches to defining growing season has to be kept in perspective as the practice of delineating wetlands on the ground was in its infancy in the 1980s and much was to be learned since then. The early approaches were largely designed to be easy to use by existing regulatory personnel who did not have the advantages of training that today's specialists have.

Evolution of the Growing Season Concept for Wetland Determinations

Frost-Free Growing Season

The Corps wetland delineation manual suggested using the "frost-free" period to identify the growing season for assessing wetland hydrology, while the growing season was actually defined by the concept of "biologic zero"* as follows: "The portion of the year when soil temperatures at 19.7 in. below the soil surface are higher than biologic zero (5°C). … For ease of determination this period can be approximated by the number of frost-free days" (Environmental Laboratory, 1987, p. A5). This recommendation was based on an incomplete understanding of wetland plant growth and/or an attempt to use the traditional concept of growing season in defining wetlands. The Corps was not alone in using this agriculture-based concept as the U.S. FWS's wetland classification also referred to a frost-free growing season and use of the National Atlas for "generalized regional delineation" (Cowardin et al., 1979). From a resource mapping perspective, this issue was not an issue since the national wetland mapping was done through photointerpretation and was not an on-the-ground exercise.

Air Temperature–Based Growing Season

In a March 1992 guidance memorandum, the Corps clarified its interpretation of growing season (Williams, 1992). Using information in local soil survey reports, the growing season could be defined for a given geographic area by determining the period when air temperatures are 28°F (–2.2°C) or more in more than 5 years in 10, except "in the South" where air temperatures 32°F (0°C) or more may be used at the discretion of the local Corps district. The higher base temperature requirement for growing season allowed more time for the vegetation to lower the water table, especially in drier-end wetlands and moist woodlands. This exception allowed Corps districts in the South some flexibility in establishing the limits of wetlands and could translate into less area to regulate in a region with an abundance of wetlands, many of which are among the more challenging wetlands to identify on the ground (e.g., seasonally saturated flatwoods). Table 1.2 gives some examples of growing seasons across the country using both the 28°F (–2.2°C) and 32°F (0°C) thresholds. In a study of an Ohio fen, Quale (1994) found that in winter, the temperature in the root zone (4 in. or 10 cm below the surface) was 42.8°F (6°C) warmer than the air temperature and that the soil temperature at 20 in. (50 cm) never fell below 41° F (5°C), a constant input of groundwater moderated soil temperatures (Amon et al., 2002).

* Biologic zero is defined by a temperature of 5°C (or 41°F) measured at approximately 20 in. (50 cm) below the surface; it is supposed to represent the temperature at which biological activity (including microbial action) ceases and reduction does not occur in the soil.

TABLE 1.2
Examples of Growing Seasons across the United States Using either 28°F or 32°F at a Frequency of More than 5 Years in 10

	28°F or Lower		32°F or Lower	
Location	**Last Freeze in Spring[a]**	**First Freeze in Fall[b]**	**Last Freeze in Spring[a]**	**First Freeze in Fall[b]**
Orono, ME	April 25	October 12	May 9	September 29
Boston, MA	March 28	November 20	April 8	November 7
Burlington, VT	April 29	October 16	May 12	October 2
Buffalo, NY	April 14	November 1	April 27	October 18
Philadelphia, PA	March 30	November 12	April 10	October 29
Baltimore, MD	April 4	November 8	April 12	October 26
Norfolk, VA	March 8	December 3	March 23	November 19
Raleigh, NC	March 26	November 11	April 13	October 26
Charleston, SC	February 23	December 4	March 16	November 18
Atlanta, GA	March 10	November 26	March 26	November 12
Orlando, FL	January 20	January 12	January 31	January 8
Birmingham, AL	March 14	November 15	March 30	November 6
New Orleans, LA	February 3	December 21	February 21	December 7
Little Rock, AR	March 7	November 20	March 22	November 9
Memphis, TN	March 4	November 22	March 23	November 11
Cincinnati, OH	April 3	November 2	April 19	October 20
Chicago, IL	April 6	November 3	April 21	October 25
Minneapolis, MN	April 19	October 14	May 1	October 4
Fargo, ND	May 3	October 3	May 13	September 25
Lincoln, NE	April 14	October 16	April 28	October 6
St. Louis, MO	April 3	November 1	April 12	October 18
Tulsa, OK	March 14	November 18	March 26	November 8
Dallas, TX	February 22	December 11	March 7	November 26
Houston, TX	February 2	December 28	February 15	December 12
Denver, CO	April 21	October 16	May 1	October 5
Boise, ID	April 28	October 15	May 10	October 5
Albuquerque, NM	April 6	November 6	April 18	October 27
Sacramento, CA	January 6	December 30	January 25	December 17
Portland, OR	February 24	December 2	March 27	November 10

Source: USDA Natural Resources Conservation Service, unpublished data for 1961–1990. For wetland delineations, the former should be used, although Corps districts have discretion to use the latter in southern states (Williams, 1992).

[a] Probability of occurring 5 years in 10 later than this date.

[b] Probability of occurring 5 years in 10 earlier than this date.

Shortcomings of Air Temperature Approach Although this approach was better than a strictly frost-free concept to defining "growing season" for wetland delineations, it was not an accurate means of assessing when native plants are growing or when soil processes are occurring that help develop hydric soil properties. It was a conservative estimate that resulted in a significant decrease in the amount of wetland that met the regulatory criteria. Soil temperatures typically lag behind air temperatures in the fall, so the end of the growing season estimates would be underestimated based on air temperature considerations (Sprecher et al., 1996). Woo and Winter (1993) reported soil temperatures above 41°F (5°C) through December for a semipermanently flooded marsh in North

Dakota, while air temperatures remained below this temperature from early November. In northern Minnesota, estimates of growing season based on 28°F and 32°F "would shorten the growing season from 1 to 3 weeks in the spring and 2 to 3 weeks in the fall" (Bell et al., 1996). In western Oregon, the growing season following the 28°F threshold would be about 3 months shorter than one based on soil temperature of 41°F measured in the upper part of the soil (10 in. or 25 cm) (Huddleston and Austin, 1996; Sprecher et al., 1996). Also while defining growing season based on the concept of biologic zero was better than using the frost-free period, it still was not technically correct as soil microbial activity occurs below these temperatures (cryophilic microbes) as does plant growth in cold regions, and certain animals are actively using some types of wetlands at temperatures below biologic zero (Flanagan and Bunnell, 1980; Grishkan and Berman, 1993; Zimov et al., 1993; Ping et al., 1996; Clark and Ping, 1997; see Rabenhorst, 2005, for a review of the concept of biologic zero and its application to wetlands).

Microflora of northern and southern soils develop under temperatures ranging from 37.4°F to 95°F (3°C to 35°C) with certain microbes active at temperatures close to the freezing point of water (Volobueu, 1964). Observations in Massachusetts floodplain wetland soils suggest that microbial action takes place essentially year-round (Peter Veneman, University of Massachusetts, personal communication, 1998). Special cloth used for microbial studies was placed in floodplain wetland soils in November and reexamined in early February and some microbial action was witnessed. Later in February, however, microbial activity increased rapidly. This is about 1 month before budburst of silver maple (*Acer saccharinum*), the predominant tree in this wetland. In studying a Wyoming subalpine meadow, Sommerfeld et al. (1993) documented microbial oxidation at temperatures below biologic zero. Studies of hydric soil hydrology and morphology in Oregon found that microbes are active year-round and that the growing season for soil microbes could not be predicted from either 28°F or 32°F air temperatures (Huddleston and Austin, 1996). In studying microbial activity in southern bottomland hardwood forests from South Carolina to Louisiana, Megonigal et al. (1993) found sufficient soil respiration and oxygen consumption to create anoxia in saturated soils in winter. The soil temperatures, however, never fell below 41°F (5°C) at 20 in. (50 cm). Based on these findings, they recommended a 12-month microbial activity season in the South for purposes of wetland hydrology assessment. Other studies documenting microbial activity during the winter include Pickering and Veneman (1984) and Groffman et al. (1992) for New England and Megonigal et al. (1996), Seybold et al. (2002), and Burdt et al. (2005) for the Southeast. Also, studies for nearly three decades of soil temperatures along the Gulf Coast have all documented that the growing season when based on biologic zero is year-round (Miller and Bragg, 2007).

Using biologic zero—41°F (5°C) soil temperature at 20 in. (50 cm)—to define the beginning of the growing season would eliminate any "growing season" for arctic and subarctic regions with shallow permafrost soils, despite the presence of tundra and taiga vegetation. Ping et al. (1992) acknowledged this problem, and the NRC (1995) noted that it also may not be appropriate to use this concept for the growing season in some temperate communities such as Minnesota bogs (Dise, 1992). Ping et al. found that microbial activity was more related to soil water content than to soil temperature, as they observed reduction when temperatures were below 35.6°F (2°C) in Alaska. Likewise, Bell et al. (1996) recorded similar findings in Minnesota mollisols, reporting reduction at 36.7°F (2.6°C). Clark and Ping (1997) recommended lowering the temperature to freezing (32°F or 0°C) based on their observations of soil-reducing conditions below 41°F (5°C). There were serious shortcomings to the concept of biologic zero as applied to soils (Rabenhorst, 2005), so changes were made in defining growing season in the Corps regional supplements (Chapter 6).

Ecological Considerations for Defining the Critical Period for Wetland Hydrology

The 1992 air temperature approach to defining growing season for wetland assessments was not scientifically sound for a few reasons. First, as mentioned earlier, the concept of biologic zero is really not accurate at least when considering soil microbial activity in cold regions. Second, there is ample evidence of wetland plant activity occurring beyond the period defined by air temperature approach for estimating it. Third, the entire concept of growing season does not consider the requirements of wetland-dependent animals that need water outside of this period. Fourth, the emphasis on growing season for defining wetland hydrology also ignores the fact that many important wetland functions are also performed during the nongrowing season (e.g., flood storage and winter wildlife habitat). From an ecological standpoint, the significant "season" or period for wetland hydrology should be based on the requirements of wetland organisms (both plants and animals, including microbes). Defining the critical hydrology period by these considerations would be superior and more scientifically sound than one based on either the frost-free period or biologic zero. Such a period might be better termed the "ecologically critical hydrologic period" or the "functionally critical hydrologic period" rather than "growing season," which emphasizes plants and ignores animal life in wetlands. The following provides a rationale for basing the critical period for defining wetland hydrology on ecological and functional grounds. Following this discussion, the latest approach to defining the growing season for regulatory purposes in the United States will be presented.

Botanical Evidence

It is well established that many native plant species begin growing well in advance of this frost-free period, especially spring bloomers, evergreen trees and shrubs, and herbs with evergreen leaves and stems (e.g., *Juncus effusus*). Growing season is plant-specific and should include growth of any kind including both shoot and root elongation. It is different for each type of plant and for plants of the same species in different locations within a state and even on one side of the mountain versus the other. For the most part, at least some native species are actively growing roots, moving nutrients and water through their cells, and even flowering before the beginning of the frost-free period. Most people know that the sap flows in sugar maples well before buds break. In southern New England, this event often begins in late February or March. Skunk cabbage (*Symplocarpus foetidus*), the dominant herb in most seasonally flooded red maple swamps throughout the northeastern United States, starts flowering about this time and does so even when snow is still on the ground. The heat emitted from cellular respiration associated with its rapid growth melts the snow or ice around it (Niering, 1985). The fact that skunk cabbage flowers and leafs out before other species emerge undoubtedly gives it a significant edge over would-be competitors (Figure 1.3).

Early spring blooming species provide visual evidence of aboveground plant activity. Besides skunk cabbage, these species include some others that grow in wetlands, such as pussy willow (*Salix discolor*), red maple (*Acer rubrum*), silver maple (*A. saccharinum*), marsh marigold (*Caltha palustris*), leatherleaf (*Chamaedaphne calyculata*), spring beauty (*Claytonia virginica*), trout lily (*Erythronium americanum*), speckled alder (*Alnus rugosa*), eastern red cedar (*Juniperus virginiana*), golden club (*Orontium aquaticum*), and Atlantic white cedar (*Chamaecyparis thyoides*). These and other plants typically bloom before the trees around them are fully leafed out. Many shrubs and trees also produce flowers before or as their leaves appear, including highbush blueberry (*Vaccinium corymbosum*), alders (*Alnus* spp.), American elm (*Ulmus americana*), ashes (*Fraxinus* spp.), oaks (*Quercus* spp.), and sweet gum (*Liquidambar styraciflua*). Table 1.3 presents examples of early blooming wetland species in various parts of the country (compare these dates with those in Table 1.2). Following an ecological approach to growing season, the beginning of this season might be defined by the average time when the buds first begin to swell for the earliest blooming wetland species. Yet evergreen trees and shrubs and herbs with overwintering green parts (e.g., shoots of sedges and grasses) undoubtedly commence growth before bud swell is noticed in deciduous woody species. Moreover, root growth prior to flower and leaf emergence and shoot development also should be included in an ecological definition of growing season. Bachelard and Wightman (1974) studying balsam poplar (*Populus balsamifera*) reported three phases of root activity prior to budburst on May 13 and such activity was initiated around March 17, about 2 months before budburst.

FIGURE 1.3 Skunk cabbage (*Symplocarpusfoetidus*) is among the first spring herbs to emerge in wetlands in the eastern United States, well before canopy closure of forested wetlands; here its leaves are opening and will eventually dominate the groundcover of this red maple (*Acer rubrum*) seepage slope wetland.

Similar processes undoubtedly occur in other species, so budburst is probably 1–2 months after initial root activity in northern climes. Budbreak in red maple and laurel oak (*Quercus laurifolia*) was observed in late January and early February in east Texas (Malone, 2010), suggesting a year-round growing season along the Gulf Coast; Miller and Bragg (2006) also recommended a 12-month growing season for coastal Texas based on long-term soil temperature data. Given its wide distribution and common occurrence in wetlands, red maple might be a good indicator for determining the beginning of the growing season across its range.

The USDA NRCS conducted a comprehensive investigation of vegetation–soil–hydrology–temperature interactions in a northern New England forest (Dudley et al., 2005). A portion of the study focused on determining the beginning of the growing season in frigid soils by comparing plant growth with soil temperature—biologic zero. During a 5-year period, buds showed noticeable swelling from 5 to 24 days prior to soil temperatures exceeding biologic zero at hydric soil sites. The results suggested that yellow birch (*Betula alleghaniensis*) might serve as a reliable indicator for the start of the growing season. Soil temperature of 41°F (5°C) at 6 in. (15 cm) and date of snow removal appeared to correlate with bud swell. In Alaska, Ping et al. (2001) also observed plant growth well before soil temperatures rose above biologic zero, when frost was still near the surface.

As far as the ecological end of the growing season for wetland species, fall flowering, seed development, and root growth activity are relevant factors. Many typical late summer–fall blooming species, like goldenrods (*Solidago* and *Euthamia*), asters (*Aster*), and beggar-ticks (*Bidens*), possess flowers well into October in the Northeast and undoubtedly are forming seeds for some time thereafter. Also, witch hazel (*Hamamelis virginiana*) flowers in the fall, with flowers observed in early December. Autumn is a prime time for root and rhizome growth as many plants continue to send nutrients to these organs for winter storage vital to next year's shoot growth. Prentki et al. (1978) reported growth of shoot bases and rhizomes in broad-leaved cattail (*Typha latifolia*) from midsummer until December in a lakeside Wisconsin marsh. In studying sedges in New York, Bernard and Gorham (1978) noticed that most shoots of beaked sedge (*Carex rostrata*) had appeared in October, but some new ones emerged in early December.

TABLE 1.3
Phenological Data on Early Blooming Wetland and Nonwetland Species in Different Parts of the Northern Conterminous United States

Location (Source)	Species	Date of First Flower
Eastern Massachusetts (Debbie Flanders, personal communication, 1998)	*Acer rubrum*	April 8–14
	Alnus rugosa	April 1–7
	Lindera benzoin	April 15–21
	Salix candida	March 25–31
	Salix discolor	April 15–21
	Symplocarpus foetidus	April 8–14
Washington, DC (Shetler and Wiser, 1987)	*Acer rubrum*	March 11[a]
	Acer saccharinum	February 22[a]
	Alnus serrulata	March 10[a]
	Cardamine hirsuta	February 27[a]
	Corylus americana	March 8[a]
	Lindera benzoin	March 27[a]
	Populus grandidentata	March 29[a]
	Salix discolor	March 15[a]
	Salix sericea	March 31[a]
	Stellaria media	January 28[a]
	Symplocarpus foetidus	February 9[a]
	Taraxacum officinale	February 1[a]
	Ulmus americana	March 2[a]
Blue Ridge Mountains, NC (Day and Mark, 1977)	*Acer rubrum*	March 11–16
	Cornus florida	April 15–22
	Quercus prinus	April 15–22
Northeastern Minnesota (Ahlgren, 1957)	*Picea glauca*	April 29–May 28
	Abies balsamea	April 30–May 8
	Larix laricina	April 25–May 9
	Thuja occidentalis	April 10–May 6
	Ulmus americana	April 25–May 8
	Betula papyrifera	April 2–23
	Betula alleghaniensis	April 2–May 16
	Acer saccharinum	April 18–30
	Acer rubrum	April 18–30
Kansas (Hulbert, 1963)	*Acer saccharinum*	January 1–March 23
	Ulmus pumila	February 7–March 26
	Ulmus rubra	February 11–April 12
	Taraxacum officinale	January 1–April 12
	Lamium amplexicaule	January 22–April 25
	Vinca minor	February 3–April 30
Great Basin, NV (Everett et al., 1980)	*Hilaria jamesii*	March 24–April 7[b]
	Atriplex confertifolia	March 28[b]
	Oryzopsis hymenoides	March 24–April 2[b]
	Chrysothamnus viscidiflorus	March 18–24[b]

Note: In southern parts of the United States, flowering occurs year-round as some species bloom during winter.
[a] Mean dates.
[b] Break in dormancy.

The average citizen in the eastern United States also realizes that the fall is an excellent time to reseed a lawn as the absence of a tree canopy (no shading) and relatively high soil moisture (due to lower air temperatures and reduced evapotranspiration) create favorable conditions for germination and root growth of cool-season grasses. Many woody plants exhibit significant root growth at this time. Lopushinsky and Max (1990) observed very small amounts of new root growth on some seedlings at a soil temperature of 32.9°F (0.5°C) and 41°F (5°C)—53% of the Pacific silver fir seedlings (*Abies amabilis*) and 37% of noble fir seedlings (*Abies procera*) developed new roots longer than 0.4 in. (1 cm) at these soil temperatures. They concluded that the ability of these firs to produce new root growth at low soil temperatures may partially explain their occurrence at relatively high elevations in the Pacific Northwest. Lyr and Hoffman (1967) reported that minimum soil temperatures for root growth range from slightly above 32°F to 44.6°F (0°C to 7°C), while optimum temperatures are from 50°F to 77° F (10°C–25°C). DeWald and Feret (1987) studying root growth of loblolly pine (*Pinus taeda*) in Virginia found that root growth continued upon cessation of shoot growth (late October) through most of the winter and, in late February, increased photosynthesis supported elevated root metabolic activity. Root activity in apple, plum, and oak trees is most active during periods of inactive shoot growth, and in temperate trees, there is considerable root growth during autumn and winter (Head, 1967; Reich et al., 1980). Mature trees of white oak (*Quercus alba*) in Missouri exhibited root growth from fall into winter until soil temperatures reached 35.6°F–41°F (2°C–5°C) and root growth was observed for 63.5% of the 145-day period between leaf drop (in the fall) and budburst (in spring) (Reich et al., 1980). Several other references that document plant growth at low temperatures include Lawrence and Oechel (1983) for root growth of arctic deciduous trees, Vézina and Grandtner (1965) for northern hardwood forest spring-herb leaf development, and Chapin and Shaver (1985) for tundra plant photosynthesis (see NRC, 1995, for additional references).

A most interesting example of plant growth in winter in New England (central New Hampshire) was reported by Muller (1978). In studying the spring ephemeral herb, trout lily, Muller described winter growth as "growth leading to the early spring development of photosynthetic tissue begins with fall root growth and continues through a long winter phase during which the shoot elongates from the perennating organ, through the soil and into the snowpack. Following snowmelt, the shoots begin rapid unfurling and maturation of the photosynthetic tissue." Vegetative growth for this species begins in mid-October with root apices elongating from the base of the bulb (corm) and the shoot elongates from mid-November to mid-December and continues through winter.

Wetzel (1990) reported that periphyton associated with aquatic macrophytes typically develops most prolifically during the autumn and winter, possibly in response to significant release of nutrients from the macrophytes. Interestingly, this stimulated microfloral growth may actually conserve nutrients within the community by preventing their release to open water, thereby recycling these vital elements and reducing possible eutrophication.

Photosynthesis may occur throughout the year in evergreen species. In North Carolina, loblolly pine and white pine (*Pinus strobus*) seedlings respired and photosynthesized year-round although rates were lowest in late January (Davis McGregor and Kramer, 1963). Lopushinsky and Kaufmann (1984) found that Douglas fir (*Pseudotsuga menziesii*) transpired at 34.3°F (1.3°C) at a rate that was 18.8% of its rate at 68.4°F (20.2°C). Kramer (1942) reported that when the soil was near freezing, pine seedlings of eastern species took up water at 14%–38% of the rate that they did at 77°F (25°C). Teskey (1982), studying Pacific silver fir, found that stomata closure occurred when temperatures fell below 34.7°F (1.5°C). Cranberry vines (*V. macrocarpon*) in Wisconsin are "alive and respiring during the dormant period" (Roper et al., 1991). Forsyth and Hall (1967) observed that cranberry leaves respire, fix CO_2, and release O_2 at a higher rate than that of respiratory oxygen consumption at low temperatures under winter flood conditions. Roper et al. further stated that "the selection of 41°F as biological zero … for an evergreen perennial vine appears arbitrary and, in all likelihood, is incorrect. This temperature does not define the lower limit of the growing season for this non-deciduous perennial plant that continues to respire and grow below 41°F." In addition, they reported that a layer of ice over the vines in winter (as a result of winter hydrology) is important to prevent desiccation of cranberry vines exposed to cold temperatures and wind. Ice or water also may prevent desiccation of other wetland species in winter.

Seeds of certain plants can germinate below 41°F (5°C). In a classic study, DeCandolle (1865) found that mustard (Cruciferae; *Sinapis alba*) germinated in 11–17 days at nearly 32°F (0°C), while peppergrass (*Lepidium sativum*) and flax (*Linum usitatissimum*) germinated in 30 and 34 days, respectively, at 35.2°F (1.8°C).

Another important consideration is that winter wetness is critically important to some plant species. Certain evergreens are highly susceptible to the effects of winter drying or drought due to evaporation from cold, dry winds. Evergreen rhododendron and evergreen bog plants (including cranberries and other members of the heath family—Ericaceae) all might significantly benefit from winter wetness. Winter flooding of cranberry bogs is a standard management practice. Loblolly pine (*P. taeda*) is well adapted to prolonged anaerobic conditions found in flatwoods that are wet from winter through early spring. In a Louisiana loblolly pine stands, Hu and Linnartz (1972) found that the wettest site had the highest site index values (most productive sites). Winter wetness increased productivity of both loblolly pine and slash pine (*Pinus elliottii*) (Haywood et al., 1990). The availability of water early in the growing season may be more important for plant growth than an adequate oxygen level in the soil. In studying the effect of waterlogging on floodplain herbs in the Netherlands, van der Sman et al. (1988) noted winter inundations among several significant factors affecting plant distribution.

Wetland plants capable of performing vital life functions and beginning reproduction during cold season wetness may have a competitive advantage over other species in terms of colonizing wetlands. The fact that evergreen species, cool-season grasses, and certain sedges grow year-round or virtually so in northern climes (Bernard and Gorham, 1978; Prentki et al., 1978; Wisconsin State Cranberry Growers Association, 1991; David Cooper, Colorado School of Mines, personal communication, 1991) makes it likely that any green plant in winter is probably active at some time (although at reduced levels). Many submerged aquatic species overwinter in an "evergreen" condition and continue basal metabolism under ice when temperatures are below 41°F–50°F (5°C–10°C), despite little or no net growth (Wetzel, 1990). The significance of winter wetness to many wetland species cannot be overlooked nor can year-round soil microbial activity. For arctic species, thawing of soil is an important event since nutrients in the frozen soil then become available for plant uptake and shoot development (Prentki et al., 1978). Finally, some areas of the country that experience a year-round plant growth include the Atlantic–Gulf Coastal Plain, Hawaii, Puerto Rico, the coastal region of the Pacific Northwest, and much of California.

Faunal Evidence

Many wetlands serve as valuable wildlife habitats during the nongrowing season—critical to the survival of many animals. Some examples follow. Evergreen forested wetlands (cedar swamps) serve as winter yards for deer and moose, northeastern coastal marshes as overwintering grounds for black ducks, and bottomland hardwood swamps as overwintering grounds for other waterfowl. In the Upper Midwest, migrating waterfowl begin arriving in pothole wetlands well before the frost-free period as temporary and seasonal potholes become inundated as snow melts during the last week of March and first week of April (Cowardin and Kantrud, 1991). In the Northeast, male red-winged blackbirds are among the first migratory birds coming back to freshwater marshes. They begin establishing their territories in early March, a month before the beginning of "growing season" defined by the air temperature approach. Floodplain forested wetlands inundated in winter and early spring are important fish habitats. Some fish species spawn during these periods, especially in the spring, while others use the flooded wetlands as nursery grounds (Leitman et al., 1991; Hoover and Killgore, 1998).

Some wetland-dependent amphibians begin breeding in vernal pool wetlands in the northeastern United States before such ponds are ice-free. The Jefferson salamander is the first amphibian to use vernal pools for breeding in the new year. Welsch et al. (1995) state that this salamander "migrates over the snow on rainy nights in late winter to slip into the pond (vernal pool) through cracks in the ice" (see photo on p. 42 of this reference for picture of Jefferson salamander migrating over snow). Klemens (1993) had to chip holes in the ice to collect specimens from the cold pond waters of southern New England.* The spotted salamander is the next salamander to use these icy ponds, entering along the ice-free edges of their natal ponds. Klemens noted that its migration occurred when soil temperatures at 12 in. (30 cm) were at least 40.1°F (4.5°C) and when the soil was warmer at the surface than it was at 12 in. (30 cm) (i.e., when soil temperature profile reversed). In southern New England, this turnover probably occurs from early to mid-March. Wood frogs are the earliest frogs to begin breeding in the Northeast. They begin their courtship choruses in similar ponds while ice is still present.

There also is significant breeding activity by some species after the "growing season." Marbled salamanders migrate to dry vernal pools in the fall (late August to October) in the Northeast (Klemens, 1993). Males leave sperm sacks on the dry pool bottom and females later arrive to fertilize the eggs with these sacks, leaving the fertilized eggs beneath leaf litter or rocks in the pool. As fall rains fill the pools, the eggs hatch and larvae feed on aquatic invertebrates (Welsch et al., 1995). Thus, late fall through winter inundation is vital to the hatching, larval development, and ultimate survival of this species. Another example of this type of life history requirement is found in the pitcher-plant bog crayfish (*Fallicambarus gordoni*). It is active from late fall through late spring in Mississippi pitcher-plant bogs when flooded and aestivates during summer drawdown (Johnston and Figiel, 1997). Mating occurs in late spring, with females retaining the fertilized eggs until fall or winter when the eggs are laid in the flooded bogs. The species mentioned earlier are just a few of the animals that depend on winter wetness for survival.

Wetland Functions Evidence

Besides providing fish and wildlife habitat, wetlands perform other important wetland functions outside the "growing season." Winter and early spring (pregrowing season) flood storage is a common function of many floodplain wetlands. Significant groundwater recharge may take place during the dormant season. Woo and Winter (1993) reported significant groundwater recharge from North Dakota pothole wetlands in early spring just after seasonal frost disappears.

Many wetland functions are carried out in all seasons and are independent of plant activity (Tiner, 1991b). Flood storage at any time during the year should be a highly valued function to people living downstream (Figure 1.4). Other wetland functions, such as shoreline stabilization, erosion control, sediment retention, and water quality renovation, continue year-round (e.g., Simmons et al., 1992). Holland (1996) notes that "it must be remembered that wetland functions are a product of all components of the wetland ecosystem (not just vascular plants), that the wetland functions year-round (not just when vascular plants are actively growing), and that critical functions (such as flood protection) will only occur at irregular intervals." A Rhode Island study of nitrate dynamics reported >80% nitrate removal from streamside wetlands in both the growing season and the dormant season (Simmons et al., 1992). Groundwater temperatures were between 43.7°F and 46.4°F (6.5°C and 8.0°C) throughout the latter season, so microbial activity was not limited by temperature. Nelson et al. (1995) observed the highest nitrate removal rate in November when water tables were high and the lowest rate in June when the deepest water tables occurred. This study suggests that microbial processes (immobilization and denitrification) were more responsible for groundwater nitrate removal than the wetland plants. Other studies have found that denitrification continues when temperatures are below 41°F or 5°C (Myrold, 1988; Zak and Grigal, 1991; Pinay et al., 1993). The hydrology of wetlands must clearly be viewed in the

* Aquatic life is active through winter in the waters below ice-covered lakes and ponds. Invertebrates including rotifers and fairy shrimp thrive at such times and fish also are active as evidenced by ice fishing.

FIGURE 1.4 Temporary storage of floodwaters by wetlands at any time of the year helps reduce the risk of flood damage.

year-round context to be most meaningful, both ecologically and functionally. Megonigal et al. (1996) and Bedford et al. (1992) also supported this view.

Current Concept of Growing Season for Wetland Delineation (2016)

After considering the facts mentioned earlier, one might reasonably ask the question: "When is hydrology not important to wetland organisms?" Given the concerns about the use of the "growing season" for defining wetland hydrology plus considering the ecological and functional significance of "nongrowing season" flooding and soil saturation, wetland hydrology should perhaps best be considered in a year-round context or at least whenever the soil is not frozen (Tiner, 1991b). The NRC (1995) reached similar conclusions and recommended that the growing season concept be replaced with another approach that better addresses the hydrologic, biotic, physical, and climatic differences in wetlands across the country. The NRC further indicated that it may be more appropriate to use a time–temperature concept. This concept would establish the duration of wetland hydrology on a regional basis related to the effect of temperature on plants, animals, soil microbes, and soil formation. Collecting the data for this type of analysis and application is not a simple, inexpensive task. More research on wetland hydrology has been recommended since any significant change in the current interpretation would affect the minimum duration of wetness requirement for wetland determinations, especially in areas subject to drainage (e.g., Skaggs, 2012).

In 2010, the Corps published a report on the definition of growing season and its use in wetland delineation (Malone and Williams, 2010). This report substantiated most of the concerns raised earlier. Although no specific recommendations were made, as this was a literature review, the authors did acknowledge that the recently published regional supplements to the Corps wetland delineation manual provided a practical approach for applying the growing season concept to wetland delineation across the country.

For the most part, the regional supplements to the Corps wetland delineation manual adopted a site-specific approach for determining the beginning and the end of the growing season (e.g., U.S. Army Corps of Engineers, 2012). Two field indicators of biological activity include (1) evidence of growth in vascular plants and (2) microbial activity, which is related to soil temperature. Sufficient evidence of vascular plant growth at the start of the growing season requires that one of the following features be observed in two or more nonevergreen plants: emergence of plants