Wetland Delineation: Overview

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Ralph W. Tiner

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Abstract

While wetlands had been drained for agricultural purposes in many regions for hundreds of years or longer, once wetlands became appreciated for the environmental services they naturally provide society (e.g., floodwater storage, water quality renovation, bank and shoreline stabilization, and provision of essential habitat for fish, aquatic invertebrates, and other animals dependent on wetlands),

R. W. Tiner (✉)
U.S. Fish and Wildlife Service (retired), Hadley, MA, USA

Institute for Wetlands and Environmental Education and Research, Inc. (IWEER), Leverett, Massachusetts, USA
e-mail: ralphtiner83@gmail.com

C. M. Finlayson et al. (eds.), *The Wetland Book*,
https://doi.org/10.1007/978-90-481-9659-3_353

people became concerned about wetland losses. Filling and the combination of dredging and filling were particularly destructive to wetland functions and altered the picturesque view that many wetlands offered, especially wetlands along coasts and large water bodies. Public concern sparked efforts to protect wetlands through three chief means: (1) acquisition of wetlands for the establishment of wildlife refuges, management areas, or nature preserves; (2) purchase of easements on private property to set aside wetlands for conservation purposes; and (3) passage of laws to directly or indirectly protect wetlands. For these purposes, it became important to identify wetlands on the broader landscape and to be able to delineate their boundaries on the ground. Such efforts often involved the production of wetland maps and required development of field-based procedures to delineate wetlands on the ground. The former is usually done for natural resource planning and land acquisition for conservation, while the latter are prepared to identify limits of "regulated" wetlands when designing construction in or near them. Before any of these activities can commence, wetlands need to be defined in such a way that they can be mapped through remote sensing techniques and by ground surveys. This contribution provides an introduction to wetland delineation with a focus on US practices. *Wetland Indicators* offers a comprehensive examination of the topic including the rationale behind many of the properties used for delineation.

Keywords
Wetland delineation · Wetland mapping · Wetland detection · Wetland identification · Wetland classification · Wetland indicators · Hydrophytic vegetation · Hydric soils · Wetland hydrology

Introduction

While wetlands had been drained for agricultural purposes in many regions for hundreds of years or longer, once wetlands became appreciated for the environmental services they naturally provide society (e.g., floodwater storage, water quality renovation, bank and shoreline stabilization, and provision of essential habitat for fish, aquatic invertebrates, and other animals dependent on wetlands), people became concerned about wetland losses. Filling and the combination of dredging and filling were particularly destructive to wetland functions and altered the picturesque view that many wetlands offered, especially wetlands along coasts and large water bodies. Public concern sparked efforts to protect wetlands through three chief means: (1) acquisition of wetlands for the establishment of wildlife refuges, management areas, or nature preserves; (2) purchase of easements on private property to set aside wetlands for conservation purposes; and (3) passage of laws to directly or indirectly protect wetlands. For these purposes, it became important to identify wetlands on the broader landscape and to be able to delineate their boundaries on the ground. Such efforts often involved the production of wetland maps and required development of field-based procedures to delineate wetlands on the ground. The former is usually done for natural resource planning and land acquisition for conservation, while the latter are prepared to identify limits of “regulated” wetlands when designing construction in or near them. Before any of these activities can commence, wetlands need to be defined in such a way that they can be mapped through remote sensing techniques and by ground surveys. This contribution provides an introduction to wetland delineation with a focus on USA practices. “Wetland Indicators” (Tiner 2016) offers a comprehensive examination of the topic including the rationale behind many of the properties used for delineation.

Wetland Mapping

With a wetland definition in place, the next step for mapping is to develop a classification system that can be used to identify the variety of wetlands in a given region. There are two basic approaches to classification: horizontal and hierarchical. A horizontal classification would identify a certain number of types and the mapper would place wetlands into one of the specified categories. The Ramsar wetland classification essentially follows this model, with the world’s wetlands placed into roughly 40 types (Ramsar Convention Bureau 1998). In contrast, the hierarchical approach is more complex in form, resembling a decision-tree where one starts with a few basic types based on general characteristics, then each main category is divided into another set of branches based on certain properties with additional branches added as different features are examined and used to separate wetlands into more unique types. The US Fish and Wildlife Service’s wetland classification is an example of this approach (Cowardin et al. 1979; FGDC Wetlands Subcommittee 2013). When considering dominance type as the final level of this type of classification, thousands of types can be recognized globally. The hierarchical approach is a flexible method that allows for a more complete description of a particular wetland and permits better representation of the diversity of wetlands.

Once the classification is in place, mappers can use remote sensing techniques (e.g., aerial image interpretation or satellite image processing, or a combination of these and other analytical methods) to produce wetland maps (Tiner et al. 2015). While wetland maps were hard-copy products in the past, the advent of computers, geographic information systems (GIS), the Internet, and web-based mapping tools have made geospatial wetland data the primary product of many wetland mapping projects. These data are posted online for users to view onscreen and print custom maps through the latter tools or to download for use in a GIS environment, such as the “wetlands mapper” (U.S. Fish and Wildlife Service) and the “NWI+ web mapper” (Association of State Wetland Managers 2014).

On-the-Ground Delineation

While it might be considered a form of mapping, field-based techniques are used to survey wetlands on a particular property or to verify the results of remotely sensed wetland mapping. For this work, onsite characteristics are typically used to identify both the presence and limits of wetlands. To verify "wetland maps" derived through remote sensing, the emphasis of the field work would be to identify various unique indicators that can be used to readily separate wetlands from nonwetlands, e.g., the primary indicators method (Tiner 1993). When evaluating a parcel of land for regulatory purposes (i.e., to establish the limits of government jurisdiction) in the USA, a more in-depth examination of site characteristics is required as such action may restrict the use of private property. For this purpose, a three-factor method (analyzing vegetation and soils, and recording observations of various signs of hydrology) is frequently used to document the presence of wetland and delineate its boundaries. Elsewhere less than three factors are used for identification. For example, in temporarily and seasonally flooded wetlands, such as the turloughs common in the karst limestone dominated landscape of western Ireland, wetland boundaries can be determined by known maximum flooded area, or presence of wetland vegetation (Sheehy Skeffington et al. 2006). Turloughs are fed by rising groundwater, typical of higher winter rainfall, with water receding in the drier summer periods. Many of these sites have the characteristics of shallow lakes during the flood period and are used as pasture for low intensity grazing in the summer.

Wetland Indicators

Aerial Imagery

Aerial photographs have been traditionally used to produce wetland maps for geographic areas of varying sizes. The traditional approach involved stereoscopic interpretation where pairs of aerial photos were viewed via a stereoscope. This allowed the interpreter to see relief (three-dimensions) which aided in detecting wetlands in depressions and broad flats and also for identifying different types based on life form (e.g., separating forests from shrub thickets). Some of the indicators that interpreters look for included the following: depressions, floodplains, broad flats (coastal plains and glaciolacustrine plains) often with creeks, drainage patterns, or pockmarked with basins, flooded areas, saturated soils, and unique plant communities that display a characteristic "photo-signature" (e.g., ericaceous shrub bogs, Atlantic white cedar swamps).

Black and white panchromatic film was the first type used for wetland mapping, but was replaced by color infrared film which became widely available and permitted better discrimination of vegetation types, especially evergreen from deciduous forests. Interpretation was done largely by delineating wetlands on acetate photo-overlays with pen and ink. Cartographers would then convert the interpretations to hardcopy maps. With the development of computers and geographic information systems, and collection of digital imagery, this traditional method has been replaced by onscreen delineation where the image analyst delineates wetlands on a computer screen to create a digital geospatial data layer that is then displayed and accessible via an online GIS data viewer or "online mapper" (e.g., ESRI Inc. 2014; US Fish and Wildlife Service 2014; Association of State Wetland Managers 2014). The available digital imagery is mostly true color (e.g., Google Earth and Bing Maps). Satellites and other sensors have been used since the 1970s to collect remotely sensed data for mapping land use and land cover including wetlands (e.g., Carter et al. 1974). Recently much progress has been made and many researchers are now using remotely sensed data to map the world's wetlands given their significance in the global carbon cycle (e.g., see Tiner et al. 2015).

Field Indicators

Since the 1970s, the USA has been actively involved in regulating uses of wetlands on private and public lands through the Federal Clean Water Act. Wetlands are considered one of the nation's waters. Consequently, the US government has probably spent more time contemplating how best to identify wetlands on the ground than any other nation. The practice of wetland delineation has evolved from the early days of wetland regulation and now there is considerable agreement amongst various Federal agencies on what is and what is not a wetland. The development of an interagency manual in 1989 was instrumental in bringing agencies together to produce a unified approach to delineation (Federal Interagency Committee for Wetland Delineation 1989). Since it was the first wetland manual adopted for mandatory use across the country, it met with strong resistance from certain interest groups as the method identified more wetland than had been regulated beforehand in some regions of the country. Nonetheless it set a standard for using a more science-based approach for wetland delineation. Today regional supplements to the Corps of Engineers 1987 wetland delineation manual are the standards used to identify wetlands (e.g., Environmental Laboratory 1987; US Army Corps of Engineers 2012, 2014). The supplements contain the list of updated wetland indicators while the manual still serves as a guide to how to evaluate plant communities on a parcel of land to make wetland determinations. The following sections summarize the common indicators of wetlands used to identify wetlands. It is important to emphasize that the US. federal delineation methods focus on the identification of vegetated wetlands, as nonvegetated wetlands such as tidal mudflats and periodically exposed shorelines of inland water bodies are considered "other waters of the United States" for regulatory purposes. The methods and field indicators are intended for use throughout the year (during wet and dry seasons, and even provide guidance for extreme droughts) and that only deep snow and frozen soils should be problematic. At the latter time, only an approximation of the location of wetlands can be made by consulting aerial imagery, existing maps, and other sources or by site characteristics. Subsequent field assessment should be conducted once snow melts and soils thaw for an accurate delineation.

Indicators of Hydrophytic Vegetation

While many plant species are unique to wetlands and can be used to positively identify wetlands, there are many others that grow in both wetlands and nonwetlands

(Tiner 1991). This makes it impossible to use vegetation alone to identify all wetlands. Nonetheless many wetlands – usually the wetter ones – can be easily recognized by their vegetation, e.g., aquatic beds, marshes, swamps, fens, and bogs. Yet other wetlands including some wet meadows, bottomland forests, flatwoods, floodplains, and disturbed wetlands typically require examination of other factors, namely soil and hydrology to verify the presence of wetland.

There are many ways to interpret vegetation with respect to its "wetlandness." One could simply look at the dominant species and determine if they are species that have a wetland preference. Alternatively one could look for the most sensitive species that are always or mostly found in wetlands or plants with morphological adaptations for life in wetlands that can be readily identified in the field. Finally one could include all species in the analysis and give individual species weight based on their affinity for wetlands and their abundance in the community. In the USA, all four approaches are used to some degree for determining if a given plant community is a "positive" indicator for hydrophytic vegetation when evaluating a site for regulation under the Federal Clean Water Act.

Hydrophytic Vegetation Indicators: US Army Corps of Engineers

Hydrophytic vegetation is just one of three factors used to verify the presence of a wetland for regulatory purposes by the US Army Corps of Engineers. Their procedure for interpreting the "wetlandness" of a plant community contains four indicators. Application of the indicators is stepwise as the amount of analysis required increases as one goes down the list. The USA has reviewed the ecological distribution of plants and assigned "wetland indicator status" to all its plants: obligate (OBL) for plant species that nearly always occur in wetlands, facultative wetland (FACW) for those that usually occur in wetlands, facultative (FAC) for those that occur in both wetlands and nonwetlands, facultative upland (FACU) for plants that usually occur in nonwetlands but may occur in wetlands, and upland (UPL) for species that almost never occur in wetlands (Reed 1988; Lichvar et al. 2014). The method also involves evaluating dominant species in different strata and in usually circular plots of variable size depending on life form (see U.S. Army Corps of Engineers 2012 for details).

The first indicator is called the "rapid test" and is based on a visual assessment of the community. If all the dominant species are rated as OBL or FACW, or a combination of these two categories, the plant community is determined to be hydrophytic (i.e., the area contains plants common to wetlands). The second indicator is the "dominance test" which involves the identification of dominant species in each of typically four strata (based on life form; i.e., tree, sapling/shrub, herb, and woody vine). In this case, when >50% of the dominant species are OBL, FACW, and/or FAC species, the community is a positive indicator for hydrophytic vegetation. The remaining indicators can only be applied in cases where hydric soil indicators and sufficient wetland hydrology indicators were found, while the plant community did not pass the first two tests for hydrophytic vegetation. The third indicator utilizes a "prevalence index test" which considers all species in the community, assigns weights based on their "wetland indicator status" (i.e., OBL = 1, FACW = 2, FAC = 3, FACU = 4, and UPL = 5) and their areal cover. The following equation is used to calculate the index:

$$PI = \frac{A_{OBL} + 2A_{FACW} + 3A_{FAC} + 4A_{FACU} + 5A_{UPL}}{A_{OBL} + A_{FACW} + A_{FAC} + A_{FACU} + A_{UPL}}$$

where

PI = Prevalence index
A_{OBL} = Summed percent cover values of obligate (OBL) plant species;
A_{FACW} = Summed percent cover values of facultative wetland (FACW) plant species;
A_{FAC} = Summed percent cover values of facultative (FAC) plant species;
A_{FACU} = Summed percent cover values of facultative upland (FACU) plant species;
A_{UPL} = Summed percent cover values of upland (UPL) plant species.

At least 80% of the total vegetation cover on the plot must be of plants that have been identified to species and have an assigned wetland indicator status (including UPL). For this indicator, a plant community with a prevalence index of 3.0 or less is a positive indicator of hydrophytic vegetation. The fourth indicator – "morphological adaptations" – allows certain FACU species to be treated as FAC species provided they possess one or more of the characteristic morphological adaptations of wetland plants (e.g., shallow roots, hypertrophied lenticels, hypertrophied stems, adventitious roots, and multistemmed trunks) and that such features are present in more than 50% of the individuals in the hydric soil area and that such adaptations do not occur in the same species growing outside the hydric soil area. When this situation is true, the FACU species is treated as FAC and the dominance test or prevalence index test are recalculated. If either test is passed, the vegetation is hydrophytic for this purpose.

Indicators of Hydric Soil

Wet soils develop certain properties that make it relatively easy to separate most wetlands from nonwetlands, although soils along low gradients (e.g., areas of low topographic relief) and disturbed soils remain somewhat problematic (Tiner 2016). Prolonged flooding and/or saturation typically leads to the accumulation of organic matter. Nearly all organic soils (Histosols; i.e., muck, peat, and mucky peat), with one exception (Folists – organic soil formed under nonsaturated conditions) are associated with wetlands. These soils are comprised of the remains of plants and characterized by thick organic deposits at least 40 cm thick but may be shallower if on bedrock, for example. In their undrained condition, they are without question a highly reliable indicator of wetland. Other soils are mineral soils characterized by some combination of sand, silt, and clay. Alternate wetting for long periods and drying of these soils creates other unique properties that can also be used to separate wetlands from nonwetlands. The degree of soil saturation influences the soil color through reduction-oxidation and precipitation of various elements. Redoximorphic features (e.g., depletions and concentrations of iron) reflect varying degrees of wetness in mineral soils (Vepraskas and Craft 2015). "Hydric mineral soil" properties include but are not limited to: (1) a gleyed matrix below the A-horizon (top mineral soil layer), (2) shallow organic soil layers (roughly 20–40 cm thick; histic epipedon), (3) soils with thick dark surfaces (black to very dark brown) underlain by low chroma subsoils possessing redoximorphic features within 30 cm of the surface, and (4) sandy soils with organic coatings or redox concentrations or depletions near the surface.

The term "hydric soil" was first used in the US Fish and Wildlife Service's wetland classification (Cowardin et al. 1979) as the presence of undrained hydric soil was recognized as an indicator of wetland. The US Department of Agriculture Natural Resources Conservation Service (NRCS) has published various documents describing field indicators of hydric soils (e.g., Vasilas et al. 2010). The indicators are periodically reviewed and updated. The regional supplements have adopted and in some cases refined these indicators for use in identifying jurisdictional wetlands. The following is a list of hydric soil indicators used in the Northcentral and Northeast Region (see the regional supplement for details; US Army Corps of Engineers 2012). The indicators are placed in four groupings: (1) all soils (regardless of texture), (2) sandy soils, (3) fine-textured soils, and (4) problematic soils. For all soils, the following are recognized as hydric soil indicators: histosol, histic epipedon, black histic, hydrogen sulfide (odor within 30 cm), stratified layers, depleted below dark surface, and thick dark surface. For sandy soils: sandy mucky mineral, sandy gleyed matrix, sandy redox, stripped matrix, dark surface, polyvalue below surface, and thin dark surface. For fine-textured soils: loamy mucky mineral, loamy gleyed matrix, depleted matrix, redox dark surface, depleted dark surface, and redox depressions. Indicators for problematic soils include 2 cm muck, coastal prairie redox, 5 cm mucky peat or peat, iron-manganese masses, Piedmont floodplain soils, mesic spodic, red parent material, and very shallow dark surface. The use of some indicators is restricted to certain portions of the region as noted in the regional supplement. The presence of hydrophytic vegetation and sufficient wetland hydrology indicators must be found before using the problematic soil indicators.

Indicators of Wetland Hydrology

In their review of federal wetland delineation methods, the National Academy of Sciences' Committee for Wetland Characterization stated that hydrophytic vegetation and hydric soils are the "common diagnostic features of wetlands" and that they should be found in all wetlands except where "specific physiochemical, biotic, or anthropogenic factors have removed them or prevented their development" (National Research Council 1995). Consequently, the presence of these two factors should be sufficient to identify most wetlands with the noted exceptions. The US federal wetland delineation approach, however, typically requires further verification of wetland through the use of "wetland hydrology indicators." Since the regulatory delineation method is establishing legal boundaries to regulate land use activities on

Table 1 List of wetland hydrology indicators (US Army Corps of Engineers 2014)

Indicator group	Indicators
Direct indicators of inundation or saturation	Water on the surface during the growing season
	Water within 30 cm of the surface during the growing season
Primary indirect indicators of inundation	Water marks
	Algal mats or crusts
	Water-stained leaves
	Water-carried debris (drift lines)
	Sediment deposits
	Sparsely vegetated concave surface
	Inundation on aerial imagery
	Iron deposits
	Aquatic fauna
	True aquatic plants (e.g., floating leaved aquatics)
	Marl deposits
Primary indirect indicators of saturation	Oxidized rhizospheres (2% or more) around living roots within 30 cm of the surface
	Odor of hydrogen sulfide within 30 cm
	Presence of reduced iron (colorimetric chemical test)
	Sign of recent iron reduction in tilled soils (2% or more redox concentrations within 30 cm of the soil surface)
	Thin muck surface (2.5 cm or less)
Secondary indicators of surface water	Surface soil cracks
	Drainage patterns (sloughs, drainageways)
	Moss trim lines
Secondary indicators of saturation	Dry season water table from 30–60 cm below the surface
	Crayfish burrows
	Saturation visible on aerial imagery
Other secondary indicators	Stunted or stressed plants
	Geomorphic position (e.g., depression, toe-of-slope, fringe of water body, or groundwater discharge site)
	Shallow aquitard (capable of producing a shallow water table within 30 cm of surface)
	Microtopographic relief (pit and low-mound topography)
	FAC neutral test (vegetation is mostly OBL and FACW species)

private property, seeking other "wetland hydrology indicators" is an additional checkpoint to help ensure that what one is seeing in terms of vegetation and soils is not a relict condition but a reflection of current hydrology. Wetland hydrology indicators can be categorized into four groups: (1) direct indicators of inundation and/or saturation (the observed presence of water on, at, or near the soil surface), (2) indirect indicators of surface water, (3) indirect indicators of soil saturation, and (4) other indicators (see Table 1). For details, consult one or more of the Corps regional supplements for wetland delineation (US Army Corps of Engineers 2014).

Delineation Methods

Primary Indicators

The primary indicators method is a rapid assessment method for wetland identification and delineation in areas without significant hydrologic modification (Tiner 1993). This approach recognizes that unique plant communities and/or soil types have formed in wetlands due to varied hydrologic regimes, climatic conditions, soil formation processes, and geomorphologic settings across the country. Within similar geographic areas, wetlands have developed characteristics different than adjacent uplands (nonwetlands) due to the presence of water in or on top of the soil for prolonged periods during most years. The visible expression of this wetness may be reflected by the plant community or in the underlying soil properties. Consequently, every wetland in its natural undrained condition should possess at least one distinctive feature that distinguishes it from the adjacent upland. This approach is not really new, but is an outgrowth of traditional methods used to recognize wetlands, including the Fish and Wildlife Service's wetland classification system (Cowardin et al. 1979). It provides a quick means of assessing the presence or absence of wetlands by looking for unique wetland characteristics. Table 2 provides a list of the primary indicators.

Three-Factor Approach

The US federal government uses three factors to identify and delineate wetlands: hydrophytic vegetation, hydric soils, and wetland hydrology. Indicators for these factors are listed above. For each plant community on a parcel of land, the three factor test is applied. To be classified as wetland, the plant community typically must exhibit a positive indicator for each factor (with few exceptions – problem situations). Hydrology indicators are separated into two groups: primary indicators (where only one is needed to verify wetland hydrology) and secondary indicators (where two or more are needed in the absence of any primary indicator). Wetland communities are separated from nonwetland communities and boundaries are marked with flagging and later surveyed, as needed, to prepare a site map showing wetlands that accompanies a permit application for construction in a wetland.

Tiered Approach

The tiered approach has been developed by some U.S. states (e.g., Massachusetts and New York). These states had a tradition of using vegetation to identify wetlands for state laws passed in the 1960s and 1970s. With subsequent knowledge gained in the use of soils for wetland identification in the 1980s, these states incorporated soils and other indicators into a tiered approach for wetland identification. The first step in this approach is to identify wetlands that can be clearly recognized by their

Table 2 List of primary indicators (Modified from Tiner 1993)

Indicator type	Indicators
Vegetation indicators	V1. OBL species comprise more than 50% of the abundant species of the plant community. (An abundant species is a plant species with 20% or more areal cover in the plant community)
	V2. OBL and FACW species comprise more than 50% of the abundant species of the plant community
	V3. OBL perennial species collectively represent at least 10% areal cover in the plant community and are evenly distributed throughout the community and not restricted to depressional microsites
	V4. One abundant plant species in the community has one or more of the following morphological adaptations: pneumatophores (knees), prop roots, hypertrophied lenticels, buttressed stems or trunks, and floating leaves. (Note: Some of these features may be of limited value in tropical USA, e.g., Hawaii)
	V5. Surface encrustations of algae, usually blue-green algae, are materially present. (Note: This is particularly useful indicator of drier wetlands in arid and semiarid regions)
	V6. The presence of significant patches of peat mosses (*Sphagnum* spp.) along the Gulf and Atlantic Coastal Plain. (Note: This may be useful elsewhere in the temperate zone)
	V7. The presence of a dominant groundcover of peat mosses (*Sphagnum* spp.) in boreal and subarctic regions. (Note: Some species may not be wetland indicators; check local authorities)
Soil indicators	S1. Organic soils (Histosols, excluding Folists) present
	S2. The presence of mineral soils with a histic epipedon
	S3. Sulfidic material (hydrogen sulfide, odor of “rotten eggs”) present within 30 cm of the soil surface
	S4. Gleyed (low chroma) horizon or dominant ped faces (chroma 2 or less with mottles or chroma 1 or less with or without mottles) present immediately below the surface layer (A- or E-horizons) and within 45 cm of the soil surface
	S5. Nonsandy soils with a low chroma matrix (chroma of 2 or less) within 45 cm of the soil surface and one of the following present within 30 cm of the surface: iron and manganese concretions or nodules; distinct or prominent oxidized rhizospheres along several living roots; low chroma mottles
	S6. Sandy soils with one of the following present: thin surface layer (2.5 cm or greater) of peat or muck where a leaf litter surface mat is present; surface layer of peat or muck of any thickness where a leaf litter surface mat is absent; a surface layer (A-horizon) having a low chroma matrix (chroma 1 or less and value of 3 or less) greater than 10 cm thick; vertical organic streaking or blotchiness within 30 cm of the surface; easily recognized (distinct or prominent) high chroma mottles occupy at least 2% of the low chroma subsoil matrix within 30 cm of the surface; organic concretions within 30 cm of the surface; easily recognized (distinct or prominent) oxidized rhizospheres along living roots within 30 cm of the surface; a cemented layer (ortstein) within 30 cm of the soil surface
	S7. Native prairie soils with a low chroma matrix (chroma of 2 or less) within 45 cm of the soil surface *and* one of the following present: thin surface layer (at least 0.625 cm thick) of peat or muck; accumulation of iron (high chroma mottles, especially oxidized rhizospheres) within 30 cm of the surface; iron and manganese concretions within the surface layer (A-horizon, mollic epipedon); low chroma (gray-colored) matrix or mottles present immediately below the surface layer (A-horizon, mollic epipedon) and the crushed color is chroma 2 or less. (Note: The native prairie region extends northward from Texas to the Dakotas and adjacent Canada)
	S8. Remains of aquatic invertebrates present within 30 cm of the soil surface in nontidal pothole-like depressions
	S9. Other regionally applicable, field-verifiable soil properties associated with prolonged seasonal high water tables (e.g., Vasilas et al. 2010)

vegetation alone. For other plant communities, hydric soil or wetland hydrology indicators are used as necessary to identify the presence of wetland.

Problem Situations

Wetland delineation during the dry season may pose problems; for those situations it is vital to consider indicators that reflect wetland boundaries during the wet season. It is important to recognize that wetland delineations performed during either the wet or dry season should produce the same boundary. While the actual boundary should not change with the seasons, the presence of certain indicators definitely varies seasonally (e.g., the presence of water).

Whenever certain rules are established to identify a given feature, there always seems to be exceptions and this is especially true for wetland delineation manuals. Problem areas may be grouped in five general categories: (1) lands used for agriculture and silviculture (problems – planted species and altered hydrology), (2) problematic hydrophytic vegetation (FACU and UPL plants growing in wetlands), (3) problematic hydric soils (hydric soils lacking indicators or nonhydric soils with low chroma subsoils), (4) wetlands that periodically lack wetland hydrology indicators, and (5) wetland-nonwetland mosaics (difficult to separate due to interspersion). Many plants that are more typical of upland (dry land) can also be found in wetlands and sometimes they dominate wetlands, so exceptions have to be made for them if following a three-factor wetland identification procedure. Since many wetlands have been drained to varying degrees, they may possess relict plant communities dominated by hydrophytic species and relict hydric soils. The effectiveness of drainage needs to be determined to see if the site currently is wet enough to be classified as wetland. Overall disturbance of wetlands and the surrounding landscape makes wetland delineation a challenging exercise. Wetland delineation manuals typically address the above situations in a special section (e.g., Difficult Wetland Situations; US Army Corps of Engineers 2012). Consult regional supplements for details as differences occur across the country (US Army Corps of Engineers 2014).

Future Challenges

While much progress has been made in defining wetland and identifying them through remote sensing and on the ground, there remain many challenges. Perhaps the first challenge in wetland delineation is to have wetland scientists reach agreement on how wetland is defined (e.g., the maximum depth of water in which a wetland occurs and the minimum wetness). There are significant differences in how wetlands are defined (e.g., Ramsar Convention and US Fish and Wildlife Service). This will be not be simple as we come from different perspectives, but given the global interest in wetlands it is at least worth consideration. At a minimum, discussions between leaders of the two main definitions (the Ramsar representatives and US Fish and Wildlife Service) should convene a meeting to discuss this topic.

While photointerpretation/image analysis has proven effective in producing relatively high-quality wetland maps, the effort required to do so is very expensive and time consuming. After 35+ years of mapping wetlands, the USA finally has produced wetland maps for the conterminous USA, yet unfortunately most of the data are from the mid-1980s. Satellite-derived data are now widely available from many sources. Moreover, improvements in remote sensing technologies and analytical procedures show promise for producing data of similar quality to aerial image-derived maps (e.g., Tiner et al. 2015), but need to be compared with those derived through conventional (manual) image analysis and ground-truthed sufficiently to determine whether they are more or less equivalent products, or at least, to better understanding their differences. This is especially important to researchers modelling the impact of climate change on wetlands and carbon cycling.

Present field techniques for delineating wetlands in the USA for regulatory processes should be streamlined as considerable effort is spent collecting data that is not really necessary for making a wetland and nonwetland determination. The tiered approach to wetland delineation offers a more efficient procedure than the three-factor method. Overall, more experience in mapping tropical and subtropical wetlands needs to be gathered to help identify the best wetland indicators for ground surveys in those regions.

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