United States Environmental Protection Agency
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Methods for Evaluating Wetland Condition

#7 Wetlands Classification

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Prepared jointly by:

The U.S. Environmental Protection Agency
Health and Ecological Criteria Division (Office of Science and Technology)

and

Wetlands Division (Office of Wetlands, Oceans, and Watersheds)

Notice

The material in this document has been subjected to U.S. Environmental Protection Agency (EPA) technical review and has been approved for publication as an EPA document. The information contained herein is offered to the reader as a review of the "state of the science" concerning wetland bioassessment and nutrient enrichment and is not intended to be prescriptive guidance or firm advice. Mention of trade names, products or services does not convey, and should not be interpreted as conveying official EPA approval, endorsement, or recommendation.

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http://www.epa.gov/ost/standards

http://www.epa.gov/owow/wetlands/bawwg

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Foreword

In 1999, the U.S. Environmental Protection Agency (EPA) began work on this series of reports entitled *Methods for Evaluating Wetland Condition*. The purpose of these reports is to help States and Tribes develop methods to evaluate (1) the overall ecological condition of wetlands using biological assessments and (2) nutrient enrichment of wetlands, which is one of the primary stressors damaging wetlands in many parts of the country. This information is intended to serve as a starting point for States and Tribes to eventually establish biological and nutrient water quality criteria specifically refined for wetland waterbodies.

This purpose was to be accomplished by providing a series of "state of the science" modules concerning wetland bioassessment as well as the nutrient enrichment of wetlands. The individual module format was used instead of one large publication to facilitate the addition of other reports as wetland science progresses and wetlands are further incorporated into water quality programs. Also, this modular approach allows EPA to revise reports without having to reprint them all. A list of the inaugural set of 20 modules can be found at the end of this section.

This series of reports is the product of a collaborative effort between EPA's Health and Ecological Criteria Division of the Office of Science and Technology (OST) and the Wetlands Division of the Office of Wetlands, Oceans and Watersheds (OWOW). The reports were initiated with the support and oversight of Thomas J. Danielson (OWOW), Amanda K. Parker and Susan K. Jackson (OST), and seen to completion by Douglas G. Hoskins (OWOW) and Ifeyinwa F. Davis (OST). EPA relied heavily on the input, recommendations, and energy of three panels of experts, which unfortunately have too many members to list individually:

- Biological Assessment of Wetlands Workgroup
- New England Biological Assessment of Wetlands Workgroup
- Wetlands Nutrient Criteria Workgroup

More information about biological and nutrient criteria is available at the following EPA website:

http://www.epa.gov/ost/standards

More information about wetland biological assessments is available at the following EPA website:

http://www.epa.gov/owow/wetlands/bawwg

List of "Methods for Evaluating Wetland Condition" Modules

Summary

The ultimate goal of classification is to reduce variation within classes to enable detection of differences between reference and impacted condition within classes as cost-effectively as possible, while minimizing the number of classes for which reference conditions must be defined. There are two different approaches to classification of aquatic resources, one that is geographically based, and one that is independent of geography but relies on environmental characteristics that determine aquatic ecosystem status and vulnerability at the region-, watershed-, or ecosystem-scale. The goal of geographically based classification schemes is to reduce variability based on spatial covariance in climate and geology, and thus topography, climax vegetation, hydrology, and soils. Geographically independent or environmentally based schemes include those derived using watershed characteristics such as land use and/or land cover, hydrogeomorphology, vegetation type, or some combination of these. It is possible to combine geographically based with hydrogeomorphic and/or habitat-based approaches. If an integrated assessment of aquatic resources within a watershed or region is desired, it also may be useful to consider intercomparability of classification schemes for wetlands, lakes, and riverine systems to promote cost-effective sampling and ease of interpretation. In general, very few definitive tests of alternative classification schemes for wetlands are available with respect to describing reference condition for either nutrient criteria or biocriteria. There are no known studies where reference conditions for both nutrient criteria and biocriteria have been assessed simultaneously. However, evidence from the literature suggests that in many cases, both geographic factors (e.g., climate, geologic setting) and landscape setting (hydrogeomorphic type) are expected to affect both water quality and biotic communities. Thus, classification should be viewed as an iterative approach, involving the initial choice of a framework as an hypothesis, validation with univariate and multivariate statistical techniques, and subsequent modification to create new classes or combine existing classes.

Purpose

The purpose of this module is to introduce the scientific basis for classifying wetlands, review some common classification schemes, and discuss their implications for establishing biological and nutrient criteria for wetlands.

Introduction

Use of a common scheme across State boundaries should facilitate more efficient collaborative efforts in describing reference condition for biota or water quality and in developing indices of biological integrity (IBIs) or other indicators (U.S. EPA 1993, http://www.epa.gov/emap/html/remap.html). We describe a series of national classification systems that could be used to provide a common framework for implementation, and suggest ways in which these classification schemes could be combined in a hierarchical fashion. Some regional approaches are also available. Adoption of any classification scheme must be considered an iterative process at this point, whereby initial results of biological or water quality sampling can be used to test and refine a given system.

Classes that behave similarly can be combined and apparent outliers examined for additional sources of variability that need to be considered. At the extreme, new classification schemes can be derived empirically through multivariate analysis. The ultimate goal is to reduce variation within classes to enable detection of differences between reference and impacted condition within classes as cost-effectively as possible, while minimizing the number of classes for which reference conditions must be defined. For example, there might be different expected conditions with respect to water quality or biological community composition for wetland classes in the absence of human impacts, and thus different criteria might be established for those classes. In assessing impacts to wetlands and determining whether restored or created wetlands were approaching a natural state, it would be most appropriate to choose a wetland from the same or targeted class for comparison.

Goals of Classification

The overall goal of classification is to reduce variability within classes caused by differences in natural condition related to factors such as geology, hydrology, and climate. The type of classification system chosen depends on the particular scientific, management, or regulatory application of interest. For the purposes of criteria development, classification is important in refining expectations for reference condition, or the state of wetlands in the absence of anthropogenic impacts.

Definition of Wetlands for Classification Purposes

Wetlands have been included in the definition of "waters of the United States" since 1975, based on an interpretation of the Clean Water Act (CWA) (Natural Resources Defense Council v. Callaway, 524 F.2d 79 (2nd Cir. 1975)). In order to apply water quality standards to wetlands, wetlands must be legally included in the scope of States' and Tribes' water quality standards programs. The U.S. Environmental Protection Agency (EPA) had requested that States' and Tribes' water quality standards be modified to include wetlands in the definition of "State waters" by the end of FY 1993. States and Tribes could accomplish this by adopting a regulatory definition of "State waters" at least as inclusive as the Federal definition of "waters of the U.S." and adopting an appropriate definition for "wetlands" (U.S. EPA 1990a, http://www.epa.gov/OWOW/wetlands/regs/quality.html). However, the CWA does not preclude States and Tribes from adopting a more expansive definition of "waters of the State" in order to meet the goals of the Act. Examples of different State approaches can be found at: http://www.epa.gov/OWOW/wetlands/partners/links.html#State Agencies.

One of the most widely accepted definitions of wetlands was adopted by the U.S. Fish and Wildlife Service (U.S. FWS) in 1979 (Cowardin et al. 1979, http://www.nwi.fws.gov/classman. html):

> *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... 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.*

Reference Concept

Under guidance for biocriteria development, reference conditions "describe the characteristics of waterbody segments least impaired by human activities and are used to define attainable biological or habitat conditions" (U.S. EPA 1990b). At least two general approaches have been defined to establish reference condition: the site-specific approach and the regional approach (U.S. EPA 1990b, http://www.epa.gov/ceisweb1/ceishome/atlas/bioindicators/). The current approach to developing water quality criteria for nutrients also emphasizes identification of expected ranges of nutrients by waterbody type and ecoregion for least-impaired reference conditions (U.S. EPA 1998, http://www.epa.gov/ost/standards/nutrient.html).

Biocriteria-related Issues

Biological criteria are narrative descriptions or numerical values that are used to describe the reference condition of aquatic biota inhabiting waters of a designated aquatic life use. They are developed by biologists and other natural resource specialists to directly assess the overall condition of an aquatic community in surface waters such as streams, rivers, lakes, estuaries, and wetlands. Biocriteria have traditionally been developed through comparison of community-level indices describing biological integrity for test sites with index ranges derived for relatively unimpacted reference sites (U.S. EPA 1990b, http://www.epa.gov/ceisweb1/ceishome/atlas/bioindicators/). Reference sites are typically stratified by landscape units such as ecoregions to reduce the variation in expected natural biological condition and to facilitate standardization of methods. Classification or identification of covariates explaining a significant fraction of variation at the waterbody scale also may be necessary. Finally, classification or ranking schemes may be necessary to describe gradients of disturbance against which biocriteria can be calibrated.

Nutrient-related Issues

The Office of Water has established a procedure to implement the Clean Water Action Plan through development of regionally-applicable nutrient criteria for each aquatic resource type (U.S. EPA 1998b, http://www.cleanwater.gov/) Development of nutrient criteria through comparison to reference conditions requires that the Nation first be stratified to reduce variability in expected condition to a reasonable range. (U.S. EPA 1998a, http://www.epa.gov/ost/standards/nutrient.html*)* For example, it would not be appropriate to set expectations for nutrient levels in peatlands receiving primarily precipitation as a water source based on background nutrient levels observed in riverine wetlands. Stratification may be necessary both at the landscape level, to take into account natural regional differences in runoff and fertility of soils influencing background levels of nutrient inputs, and at the scale of water-bodies, to take into account differences in source water characteristics and retention time related to sensitivity of response. As wetlands water quality criteria are developed for other constituents (e.g., clean sediments) regionalization of criteria and related classification issues will be important for these as well.

An alternative definition of the reference concept has been developed for the hydrogeomorphic assessment (HGM) approach, used to describe expectations for wetland function by wetland hydrogeomorphic type and region. Under the HGM approach, "(r)eference wetlands are actual wetland sites that represent the range of variability exhibited by a regional wetland subclass as a result of natural processes and anthropogenic disturbance. In establishing reference standards, the geographic area from which reference wetlands are selected is the reference domain." For practical purposes, HGM practitioners define reference standard as: "conditions exhibited by a group of reference wetlands that correspond to the highest level of functioning (highest, sustainable level of functioning) across the suite of functions performed by the regional subclass. By definition, the highest level of functional capacity is assigned a functional capacity index value of 1.0." (see Smith et al. 1995, http://www.wes.army.mil/el/wetlands/pdfs/wrpde9.pdf).

Existing Wetland Classification Schemes

There are two different approaches to classification of aquatic resources, one that is geographically based and one that is independent of geography, but relies on environmental characteristics that determine aquatic ecosystem status and vulnerability at the region, watershed, or ecosystem scale (Detenbeck et al. 2000). Ecoregions (including "nutrient ecoregions") and ecological units represent geographically based classification schemes that have been developed and applied nationwide (Omernik 1987, Keys et al. 1995). The goal of geographically based classification schemes is to reduce variability based on spatial covariance in climate and geology, as well as in topography, climax vegetation, hydrology, and soils. For some regions of the country, ecoregions have been refined to explain a finer scale of spatial variation (e.g., Omernik and Gallant 1988). Geographically independent or environmentally based schemes include those derived through watershed characteristics such as land-use and/or land-cover (Detenbeck et al., 2000), hydrogeomorphology (Brinson 1993), vegetation type (Grossman et al. 1998, http://consci.tnc.org/library/pubs/class/toc1.html), or some combination of these (Cowardin et al. 1979). Both geographically dependent and environmentally based schemes have been developed for single scales, and for a nested hierarchy of scales (Detenbeck et al. 2000).

Geographically Based Classification Schemes

Regional classification systems were first developed specifically for the United States by land management agencies. The U.S. Department of Agriculture (USDA) has described a hierarchical system of Land Resource Regions and Major Land Resource Areas for agricultural management based mainly on soil characteristics (USDA SCS 1981). Ecoregions were then refined for USDA and the U.S. Forest Service based on a hierarchical system in which each of several environmental variables such as climate, landform, and potential natural vegetation were applied to define different levels of classification (Bailey 1976). Subsequently, Omernik and colleagues developed a hierarchical nationwide ecoregion system to classify streams, using environmental features they expected to influence aquatic resources as opposed to terrestrial resources (Hughes and Omernik 1981, Omernik et al. 1982). The new ecoregion system was based on an overlay of "component maps" for land use, potential natural vegetation, land-surface form, and soils, and a subjective evaluation of the spatial congruence of these factors as compared to the hierarchical approach used by Bailey, which relied only on natural features (not land use). Omernik has produced a national map of 76 ecoregions defined at a scale of 1:7,500,000 (Figure 1) (Omernik 1987; http://water.usgs.gov/GIS/metadata/usgswrd/ecoregion.html). More detailed regional maps have been prepared at a scale of 1:2,500,000 in which the most "typical" areas within each ecoregion are defined. Cowardin et al. (1979) have suggested an amendment to Bailey's ecoregions to include coastal and estuarine waters (Figure 2). In practice, Omernik's scheme has been more widely used for classification of aquatic resources such as streams, but few examples of applications are available for wetlands.

Finally, an attempt has been made to integrate approaches across Federal agencies to produce regional boundaries termed ecological units (Keys et al. 1995). Information has been combined on climate, landform, geomorphology, geology, soils, hydrology, potential vegetation, and water to produce a nested series of boundaries for the eastern United States, but different combinations of environmental parameters are emphasized at each hierarchical level of classification. This scheme was developed to explain variation in both terrestrial and

Figure 1: Map of Omernik aquatic ecoregions.

aquatic systems and is consistent with a more comprehensive strategy to classify lotic systems down to the level of stream reaches (Maxwell et al. 1995). The mapped system for the eastern United States includes classification at the following levels:

domain (n=2) > divisions (n=5) > provinces (n=14) > sections (n=78) > subsections,

where sections are roughly equivalent to half of an ecoregion as defined by Omernik (Figure 3). For lotic systems, additional spatial detail can be added by defining watersheds (at the level of landtype associations), subwatersheds (at the level of landtypes), valley segments, stream reaches, and finally channel units (Maxwell et al. 1995). In reality, all watersheds are not nested neatly within subsections, and may cross subsection boundaries.

Some States and Tribes have chosen to refine the spatial resolution of Omernik's ecoregional boundaries for management of aquatic resources (e.g., Region 3 and Florida, http://www.dep.state.fl.us/water/slerp/bio/sbecoreg.htm). For example, the State of Florida has defined subecoregions for streams based on analysis of macroinvertebrate data from 100 reference sites. Efforts are currently under way to define ecoregions for Florida wetlands based on variables influencing the water budget (M. Brown, personal communication). Potential source geographic information system (GIS) data layers to support such an effort are described below.

Environmentally Based Classification Systems

Hydrogeomorphic classification system(s)

Brinson (1993) has defined a hydrogeomorphic classification system for wetlands, based on geomorphic setting, dominant water source (Figure 4), and dominant hydrodynamics (Figure 5; http://www.wes.army.mil/el/wetlands/regdoc.html). Seven classes have been described: riverine, depressional, slope, mineral soil flats, organic soil flats, tidal fringe, and lacustrine fringe (Smith et al. 1995). Depressional systems, as the name implies, are located in topographic depressions where surface water can accumulate (Figure 6a). Depression wetlands can be further classified based on presence of inlets or outlets and primary water source as closed, open/groundwater, or open/surface water. Lacustrine fringe wetlands are located along lake shores where the water elevation of the lake determines the water table of the adjacent wetland. Great Lakes coastal wetlands represent one important region of lacustrine fringe wetlands (Figure 6b). These coastal systems are strongly influenced by coastal forming processes, and, as such, have been further classified by geomorphic type through various schemes (Jaworski and Raphael 1979, and others summarized in Michigan Natural Features Inventory 1997). These geomorphic coastal positions will further influence the predominant source of water and degree and type of energy regime (riverine vs. seiche and wave activity). Tidal fringe wetlands occupy a similar position relative to marine coasts and estuaries and where the water level is influenced by sea level (Figure 6c). Tidal fringe wetlands can be broken down further based on salinity into euhaline vs. mixohaline subclasses. Slope wetlands occur on slopes where groundwater discharges to the land surface but typically do not have the capacity for surface water storage (Figure 7). Riverine wetlands are found in floodplains and riparian zones associated with stream channels (Figure 6d). Riverine systems can be broken down based on watershed position (and thus hydrologic regime) into tidal, lower perennial, upper perennial, and nonperennial subclasses. Mineral soil flats are in areas of low topographic relief (e.g., interfluves, relic lake bottoms, and large floodplain terraces) with precipitation as the main source of water (Figure 6e). In contrast, the topography of organic soil flats (e.g., peatlands) is controlled by the vertical accretion of organic matter (Figure 6f). The HGM classification system is being further refined to the subclass level for different regions or states and classes (Cole et al. 1997, http://www.wes.army.mil/el/wetlands/regdoc.html). In addition to the classi-

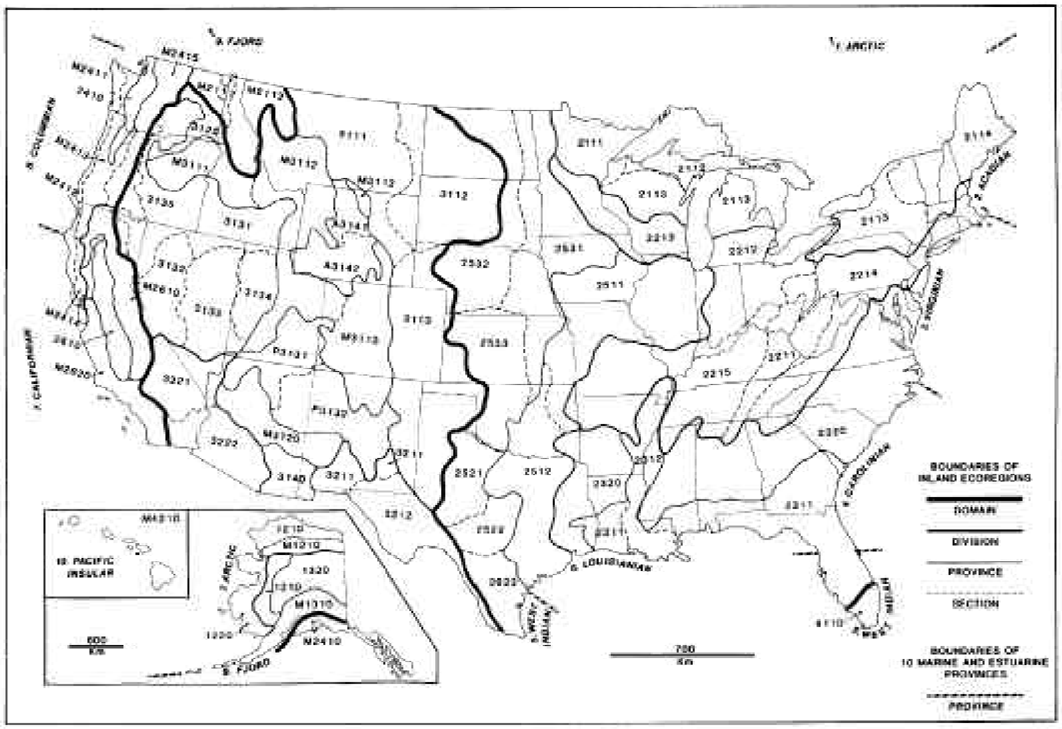


Figure 2: Map of Bailey ecoregions with coastal and estuarine provinces, from Cowardin et al., 1979.

Figure 3: Examples of first four hierarchical levels of Ecological Units: domain, division, province, and section, from US EPA Environmental Atlas.

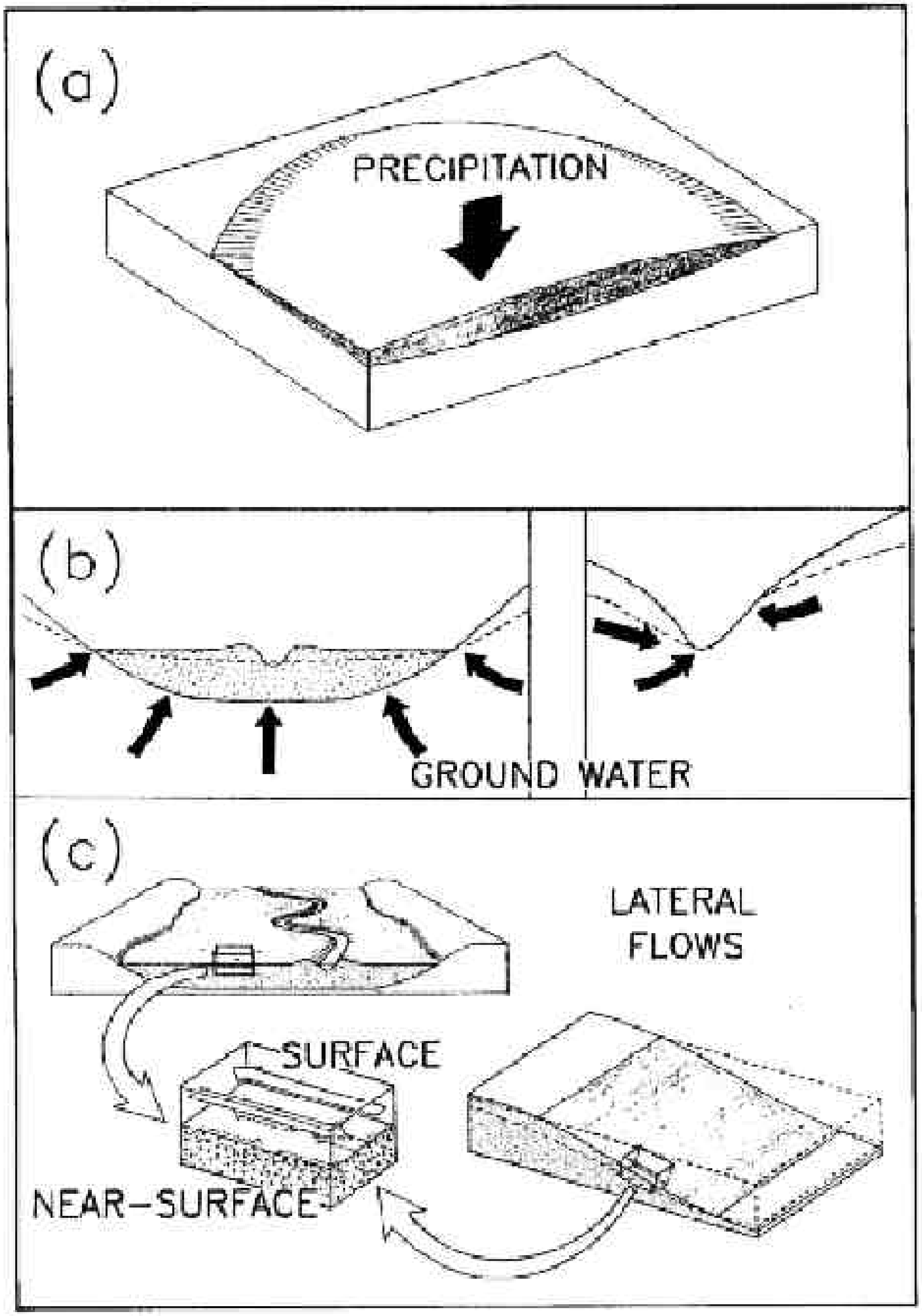


Figure 4: Dominant water sources to wetlands, from Brinson 1993.

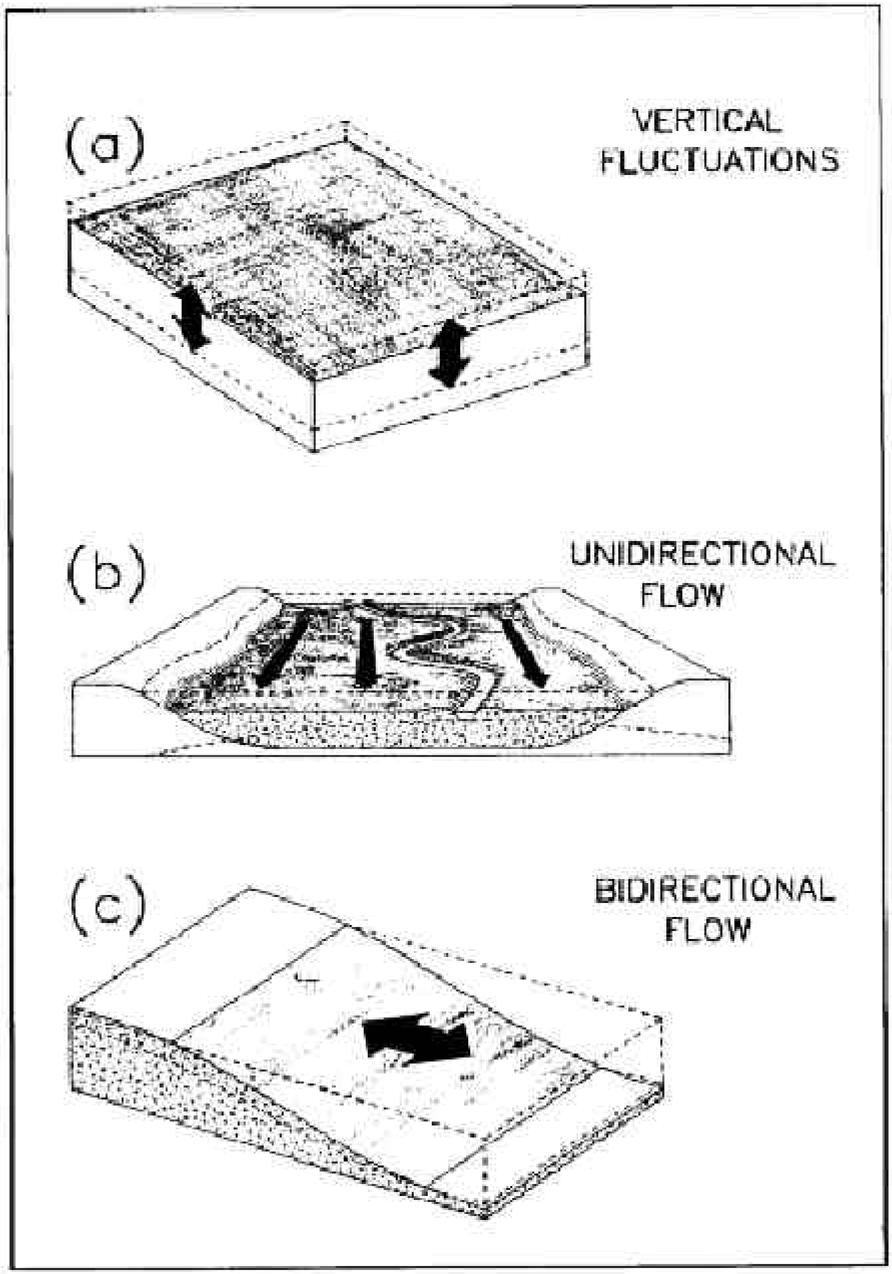
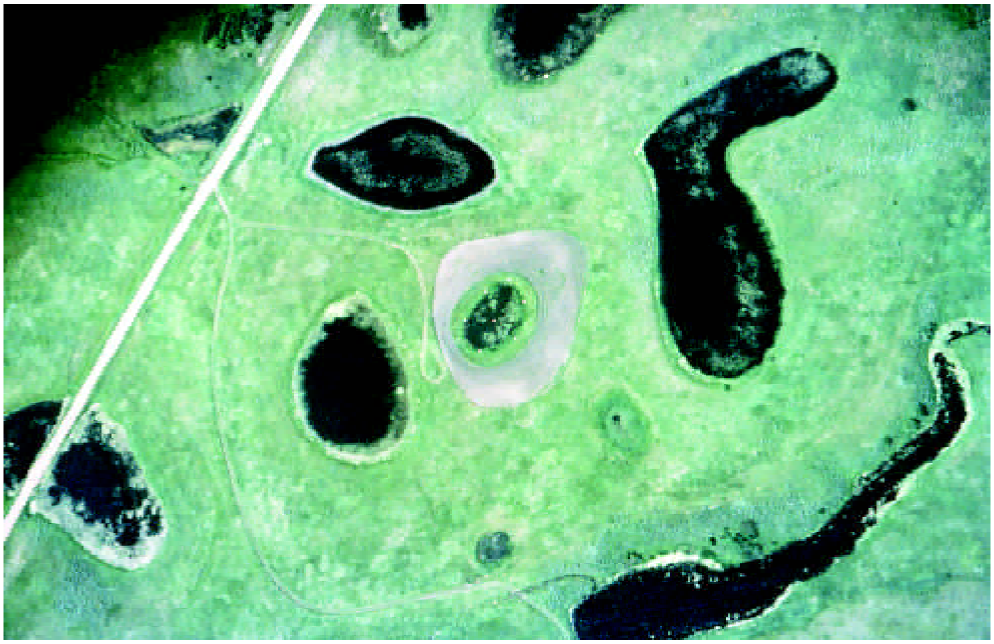


Figure 5: Dominant hydrodynamic regimes for wetlands based on flow pattern, from Brinson 1993.



a) Depressional wetland

b) Lacustrine fringe

Figure 6: Examples of hydrogeomorphic wetland classes: a) Depressional wetland, b) Lacustrine fringe, c) Tidal fringe, d) Riverine wetland, e) Mineral flats wetland, and f) Organic flats wetland.

Figure 6 (continued) (c) Tidal fringe

fication factors described above, the Army Corps of Engineers (ACE) suggests using parameters such as the degree of connection between the wetland and other surface waters (depressional wetlands), salinity gradients (tidal), degree of slope or channel gradient (slope and riverine wetlands), position in the landscape (riverine, slope), and a scaling factor (stream order, watershed size or floodplain width for riverine subclasses). In some cases, existing regional schemes could be used as the basis for subclass definition (e.g., Stewart and Kantrud 1971, Golet and Larson 1974, Wharton et al. 1982, Weakley and Schafale 1991, Keough et al. 1999). The ACE is currently defining regions for refinement of HGM classes based on factors such as climate and geology.

The HGM classification system has been applied primarily for a functional assessment strategy termed the HGM approach (Smith et al. 1995, http://www.wes.army.mil/el/wetlands/pdfs/wrpde9.pdf). However, the same environmental parameters that influence wetland functions also determine water regime and background water quality, which in turn drive wetland habitat structure and community composition and the timing of biotic events. Thus, the HGM classification system can serve as a basis for partitioning variability in reference trophic status and biological condition, as well as defining temporal strategies for sampling.

Habitat-based classification systems

Wetland habitat types are described very simply but coarsely by the Circular 39 definitions, ranging from temporarily flooded systems to ponds (Shaw and Fredine 1956) (see Appendix A-2). A more refined hierarchical classification system is available based on vegetation associations; one system developed by the Nature Conservancy for terrestrial vegetation (including some wetland types) has been adopted as a standard for Federal agencies (Grossman et al. 1998, http://consci.tnc.org/library/pubs/class/toc1.html). Vegetation associations have been used to classify Great Lakes coastal wetlands within coastal geomorphic type (Michigan Natural Features Inventory 1997).

Cowardin classification system

The U.S. Fish and Wildlife Service (FWS) classification system (Cowardin et al. 1979) was developed as a basis for identifying, classifying, and map-

Figure 6 (continued) (d) Riverine wetland

ping wetlands, other special aquatic sites, and deepwater aquatic habitats, and has since been established by both Federal and some State agencies as the official system for wetland inventory and classification. The Cowardin system combines a number of approaches incorporating position, hydrologic regime and habitat (vegetative) type (Figure 8a,b; http://www.nwi.fws.gov/classman.html). Wetlands are categorized first by landscape position (tidal, riverine, lacustrine, and palustrine), then by cover type (e.g., open water, submerged aquatic bed, persistent emergent vegetation, shrub wetlands, and forested wetlands), and then by hydrologic regime (ranging from saturated or temporarily-flooded to permanently flooded). Modifiers can then be added for different salinity or acidity classes, soil type (organic vs mineral), or disturbance activities (impoundment, beaver activity, etc.). Thus, the Cowardin system includes a mixture of geographically-based factors, proximal forcing functions (hydrologic regime, acidity), anthropogenic disturbance regimes, and vegetative outcomes. In practice, the Cowardin system can be aggregated by combination of HGM type and predominant vegetation cover if digital coverages are available (Ernst et al. 1995).

Figure 6 (continued) (e) Mineral flats wetland

Comparison of Environmentally Based Classification Systems

The Anderson Level 2 land-cover classification system, used in classifying cover from satellite imagery or aerial photo interpretation, can be described as a combination of Cowardin classes (Appendix A-1) (Anderson et al. 1976). Anderson's land-cover classification system has been merged with a modification of Cowardin's system for freshwater (Great Lakes) and marine coastal systems as part of NOAA's Coastal Change Analysis Program (C-CAP; NOAA 1995, http://www.csc.noaa.gov). Comparisons of Cowardin's classification system with other earlier methods can be found in Cowardin et al. (1979; http://www.nwrc.gov/diglib.html) (see also Appendix A-2).

If an integrated assessment of aquatic resources within a watershed or region is desired, it also may be useful to consider intercomparability of classification schemes for wetlands, lakes, and riverine systems to promote cost-effective sampling and ease of interpretation. The HGM approach could intergrade readily with a finer level of classification for lake type because lentic systems are separated out as lacustrine fringe or depressional wetlands based on lake or pond size and influence of water level on the adjacent wetland. Lacustrine classification systems for water quality have included geography (climate + bedrock characteristics, Gorham et al. 1983) or hydrologic setting (Winter 1977, Eilers et al. 1983) as factors for categorization. For Great Lakes coastal wetlands, McKee et al. (1992) suggest a modification of Cowardin's system, incorporating landscape position (system), depth zone (littoral vs. limnetic subsystems), vegetative or substrate cover (class and subclass), and modifiers of ecoregions, water level regimes, fish community structure, geomorphic structure, and human modification. In contrast, the Michigan Natural Features Inventory (1997) categorizes Great Lakes coastal wetlands by Great Lake, then by nine unique geomorphic types within lakes, then by vegetative association.

Figure 6 (continued) (f) Organic flats wetland

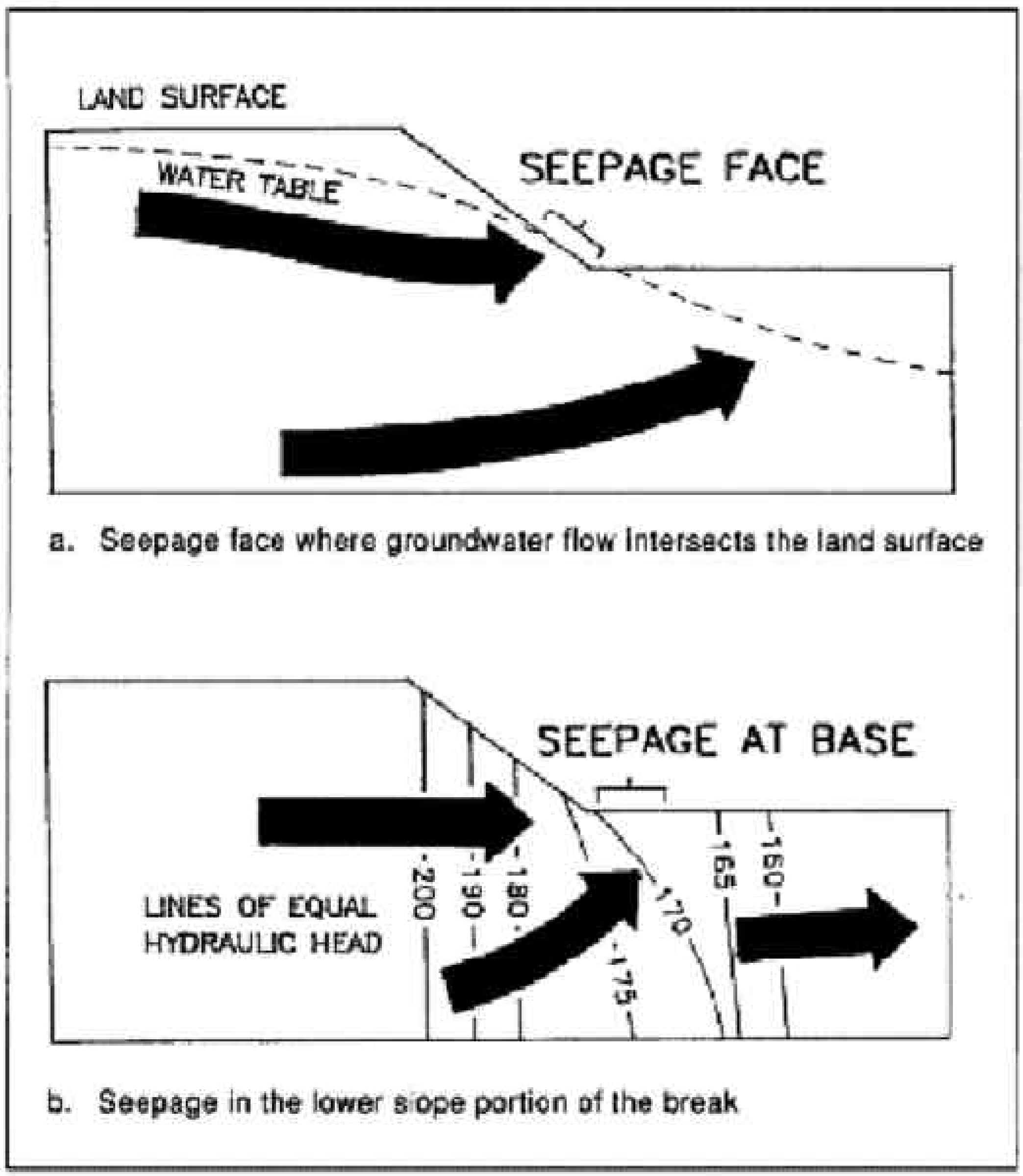


Figure 7: Interaction with break in slope with groundwater inputs to slope wetlands, from Brinson 1993.

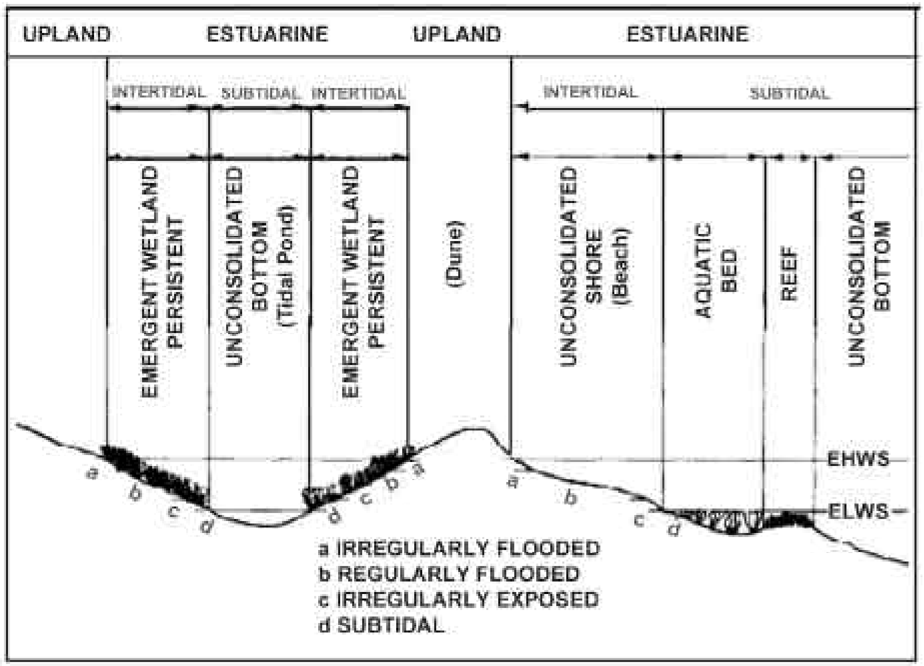


Figure 8: a) Cowardin hierarchy of habitat types for estuarine systems.

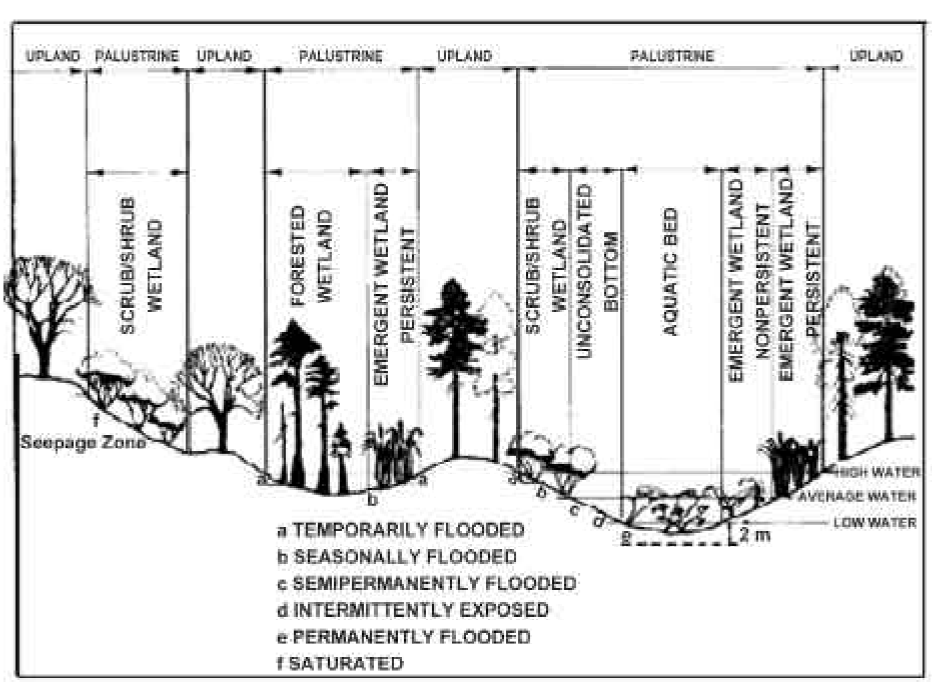


Figure 8: b) palustrine systems, from Cowardin et al. 1979.

For lotic systems, Brinson et al. (1995) describes an approach to further classify riverine classes into subclasses based on watershed position and stream size/permanence. This strategy is consistent with current monitoring efforts to develop stream IBIs, which typically use stream order as a surrogate for watershed size in explaining additional background variation in IBI scores (U.S. EPA 1996). A more detailed classification of stream reach types, based on hydrogeomorphic character, is described by Rosgen (1996). This classification scheme has been predominantly applied to assessments of channel stability and restoration options, and not to development of criteria. The Bureau of Land Management has described a cross-walk between riparian and wetland classification and description procedures (Gephardt et al. 1990); see http://www.rwrp.umt.edu/Montana.html for a regional application.

Combinations of Geographic and Environmentally Based Approaches

It is possible to combine geographically based and hydrogeomorphic and/or habitat-based approaches. For example, a scheme could be defined that nests Cowardin (Cowardin et al. 1979) vegetative cover class within HGM class within ecoregion. Maxwell et al. (1995) have defined a scheme for linking geographically based units based on geoclimatic setting (domains => divisions => provinces => sections => subsections) to watersheds and subwatersheds (roughly equivalent to landtype associations), and thus to riverine systems composed of valley segments, stream reaches, and channel units, or to lacustrine systems composed of lakes, lake depth zones, and lake sites/habitat types.

Maxwell et al. (1995) also define a series of fundamental hydrogeomorphic criteria for classifying wetlands based on Brinson (1993) and Winter (1992), including physiography (landscape position), water source, hydrodynamics, and climate. The first three are similar to the HGM classification system, whereas moisture regimes and soil temperature regimes are generally consistent at the province level (see summary tables in Keys et al. 1995). Finer scale variation in landforms is captured at the level of sections and below, which in turn will determine the dominance of different hydrogeomorphic classes of wetlands and associated surface waters (lakes and rivers).

Characteristics and relative advantages and disadvantages of the different classification systems are summarized in Table 1.

Sources of Information for Mapping Wetland Classes

In order to select wetlands for sampling, whether in a targeted, random, or random-stratified design, it is necessary to have a record of wetland locations to choose from, preferably categorized by the classification system of interest. For some but not all portions of the country, wetlands have been mapped from aerial photography through the National Wetlands Inventory (NWI) system maintained by the U.S. Fish and Wildlife Service. In other cases, individual States have developed inventories, or researchers have developed lists of restricted types wetlands within a given region, e.g., Great Lakes coastal wetlands (Herdendorf et al. 1981).

In order to sample these mapped wetland areas in a random fashion such that the results are representative for all wetlands, all wetland areas, or wetlands of a specified type within a region, it is necessary to have a list of the wetland population,

Table 1: Comparison of Landscape and Wetland Classification Schemes

Classification scheme	Scale	Hierarchical?	Levels of strata	Advantages	Disadvantages	Potential links with other schemes
Bailey=s ecoregions	Nationwide	Yes	Domains Divisions Provinces Sections	Only natural attributes included Digital maps	Terrestrial basis Untested for wetlands No hydrology	Could form first strata for any of the schemes below ecological units
Omernik ecoregions	Nationwide	No	Ecoregions Subecoregions	Digital maps	Combines land use with natural attributes Untested for most wetlands No hydrology	Could form first strata for any of the schemes below ecological units
Ecological units (Maxwell et al. 1995)	Nationwide	Yes	Domain Divisions Provinces Sections Subsections	Digital maps	Greater number of strata and units than for ecoregions Untested for wetlands	Could form first strata for any of the schemes below ecological units Ties to classification schemes already defined within hydrogeomorphic types
U.S. ACE hydrogeomorphic Classes	Nationwide at class level; regionalized at subclass level	Yes - limited	Class Subclass	Specific for wetlands	Subclasses not comparable across different regions	Intermediate strata between geographic and habitat-scale
Rosgen channel types	Nationwide	Yes	Level I Level II	Captures differences in hydrologic regime for riverine wetlands	More focused on instream channel form than riparian characteristics Riverine only Not mapped	Intermediate strata between hydro-geomorphic type and habitat-scale
Anderson land-cover classes	Nationwide	Yes	Level I Level II Level III	Common basis for land-use/land-cover mapping	Not functionally based	Cross-walk with NWI system possible
Circular 39 classes	Nationwide	No	Class	Popular recognition	Mixture of criteria used to distinguish classes Not mapped	Strata below geographic but contains mixture of hydrogeomorphic type and habitat type
National Wetland Inventory	Nationwide	Yes	System Subsystem Class Subclass Hydrologic modifier Other modifiers	Digital maps available for much of Nation (but smallest wetlands omitted)	Inconsistencies in mapping water quality modifiers Limited consideration of hydrogeomorphic type	Strata below geographic Hydrogeomorphic class could be improved by link with HGM system
Vegetation associations	International	Yes	System Formation class Formation subclass Formation group Formation subgroup Formation alliance Association	Consistency across terrestrial and aquatic systems	Not functionally based No digital maps Taxa specific	Could be used as lowest level within other schemes

preferably with areas attached. A GIS allows one to automatically produce a list of all wetland polygons or all wetland polygons by type within a specified region. Sources of digital information for mapping and/or classifying wetlands in a GIS are presented in Appendix B. In areas for which digital NWI maps do not yet exist, potential wetland areas can be mapped using GIS tools to predict relative wetness (e.g., Phillips 1990). It should be noted that where hydrology has been significantly altered, e.g., through ditching, tiling, or construction of urban stormwater systems, areas of potential wetlands will have been removed already. Similarly, although there are no current maps of wetlands by hydrogeomorphic class, these could be derived through GIS techniques using a combination of wetland coverages, hydrography (adjacency to large lakes and rivers), and digital elevation models to derive landforms (mineral and organic soil flats) and/or landscape position (slope and depressional wetlands; see http://www.geog.le.ac.uk/jwo/research/LandSerf/index.html for free terrain analysis software, and example applications of terrain analysis for identifying landforms at: http://www.undersys.com/caseGW.html , http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/fels_john/fels_and_matson.html).

Empirical Classification Methods

Classification should be viewed as an iterative approach, involving the initial choice of a framework as a hypothesis, validation with univariate and multivariate statistical techniques, and subsequent modification to create new classes or combine existing classes. Best professional judgment can be used to generate a hypothetical set of classes, using techniques such as the Delphi approach to gain consensus (Linstone and Turoff 1975). The Delphi approach is a process to extract the collective intelligence of a group of experts who may have a wide range of backgrounds, expertise, and opinions. Responses to the Delphi process, either via interviews or questionnaires, are anonymous, and must be summarized by a third party and redistributed back to the group of experts for reconsideration until a consensus is reached. The process can be time-intensive, requiring up to four rounds of questioning to achieve consensus (or the closest approximation possible). The process is appropriate when input is needed from a range of experts, frequent group meetings are not feasible because of time or cost, or face-to-face communications may be hindered by the strength of disagreements and/or by the personalities of participants.

To produce a more objective framework, it is possible to sample a suite of reference wetlands randomly, and then classify sites based on physical, chemical, and/or biological characteristics after the fact through parametric techniques such as cluster analysis, discriminant function analysis, detrended canonical correlation analysis (DCCA), and/or nonparametric techniques such as nonmetric dimensional scaling (NMDS). Cluster analysis is an exploratory technique that groups similar entities, e.g., by community composition, in a hierarchical structure. Discriminant function analysis can be used to objectively define those attributes of groups responsible for intergroup differences. Detrended canonical correlation analysis is a parametric multivariate technique for relating multiple explanatory variables such as site characteristics to multiple response variables such as species abundances, or metrics within an index of biological integrity. It corrects for the "arch" effect of regular canonical correlation analysis (CCA) that results from the unimodal distribution of species along environmental gradients. NMDS is a nonparametric technique (i.e., does not rely on the normal distribution of underlying data) that can be used to order sites along gradients based on species composition differences, then independently determine which environmental variables significantly covary with community gradients. Although these techniques can be used in an exploratory fashion, they can also be applied with a second set of data to confirm an initial classification scheme:

Option 1:
CHOOSE CLASSES => RANDOMLY SAMPLE => TEST DATA TO CONFIRM GROUPINGS

Option 2:
RANDOMLY SAMPLE FULL POPULATION => DERIVE CLASSES EMPIRICALLY FROM SUBSET 1 => TEST VALIDITY OF CLASSES WITH SUBSET 2.

Numerous examples of the application of empirical classification schemes for other aquatic ecosystem types can be found in the September 2000 issue of the *Journal of the North American Benthological Society* (vol. 19, issue 3). Multivariate analysis techniques are available in common statistical packages such as SAS (SAS Institute 1979), SPSS (Nie et al. 1975), and BMDP (Dixon 1981). In addition, more specialized software exists that is specifically geared towards the analysis of biological community data, including CANOCO (ter Braak and Šmilauer 1998), PC-ORD (MJM

Software Design 2000), TWIN-SPAN (Mohler 1991), and others (see http://www.okstate.edu/artsci/botany/ordinate/software.htm for partial listing).

State of the Sciences

Very few definitive tests of classification systems for wetlands monitoring have been completed, although a number of monitoring strategies have been implemented based on preselected strata. Monitoring efforts to develop or assess biological criteria have generally used a combination of geographic region and hydrogeomorphic class or subclass (Appendix C). The ability of geographic or hydrogeomorphic classes to discriminate among biological community types can be tested a priori through multivariate analysis. Cole and colleagues (1997) have measured significant differences in hydrologic attributes among riparian wetlands of different HGM subclasses in Pennsylvania, which are expected to control vegetation type. Subsequent work on macroinvertebrate communities found similarity among sites within the same HGM subclass. However, there were important microhabitat differences within HGM subclasses, e.g., between soil and stream habitats in headwater floodplains, Habitats in different HGM subclasses but with similar hydroperiods (ephemeral pools in riparian depressions and saturated soils in slope wetlands) were nearly 50% similar in community composition. Overall, soil organic matter and site wetness showed strong relationships with invertebrate community composition and could probably be used as indices of similarity across sites (Bennett 1999). Researchers with the Michigan Natural Features Inventory have examined vegetation associations among HGM subclasses of coastal wetlands within different Great Lakes using TWINSPAN, a cluster analysis package (Michigan Natural Features Inventory 1997). Associations were found to differ by climate regime (N vs. S, roughly at the province level), soil pH (related to bedrock type), connectivity to the lake, and degree of human disturbance. Apfelbeck (1999) classified Montana wetlands by hydrogeomorphic subclass within ecoregion for development of IBIs based on diatoms and macroinvertebrate communities. Multivariate analysis of these communities showed good agreement overall with preselected classes, although some classes were indistinguishable for diatoms (riparian, open lakes, closed basins), whereas others had to be further subdivided based on extremes of water chemistry/source water type (saline, closed basin-alkaline, closed basin-recharge vs. closed basin-surface water) or water permanence (ephemeral).

Analysis of vegetative associations has been used to derive empirical classifications based on factors such as landscape position, water source, climate, bedrock, and sediment hydraulic conductivity (Weakley and Schafale 1991, Nicholson 1995, Halsey et al. 1997, Michigan Natural Features Inventory 1997). Only one case of classification based on wetland macroinvertebrate composition was found. For Australian wetlands, wetland classes grouped by macroinvertebrate communities were distinguished by water chemistry extremes (low pH, high salinity), degree of nutrient enrichment, and wetland color (Growns et al. 1992).

In some cases, e.g., northern peatlands, the classification criteria that are derived on the basis of vegetation associations are less powerful in discriminating among nutrient regimes (e.g., Nicholson 1995); this may be particularly true where variation in vegetation type is related to differences in major ion chemistry and pH. However, controls may differ regionally. For southern pocosins, short and tall pocosins differ in seasonal hydrology but not soil chemistry, whereas pocosins and swamp forest differ strongly in soil nutrients (Bridgham and Richardson 1993). For some potential indicators of nutrient status such as vegetation N:P ratios, indicator thresholds will be consistent across species (Koerselman and Meuleman 1996), whereas others (tissue nutrient concentrations) vary across functional plant groupings with different life history strategies, indicating potential differences in sensitivity to eutrophication (McJannet et al. 1995).

Sensitivity to nutrient loading (as evidenced by differences in nutrient removal efficiency) may also be related to differences in hydroperiod among wetlands. Wetland mesocosms exposed to pulse discharges had higher nutrient removal rates than those exposed to continuous flow regimes (Busnardo et al. 1992). Mineralization rates of carbon, nitrogen, and phosphorus differ significantly among soils from northern Minnesota wetlands, related to an ombrotrophic to minerotrophic gradient (i.e., degree of groundwater influence) and aeration status. The physical degree of decomposition of organic matter serves as an integrating variable that can be used to predict carbon, nitrogen, and phosphorus mineralization rates (Bridgham et al. 1998).

In general, very few definitive tests of alternative classification schemes for wetlands are available with respect to describing reference condition for either nutrient criteria or biocriteria. There are no known studies where reference conditions for both nutrient criteria and biocriteria have been assessed simultaneously. However, evidence from the literature suggests that in many cases, both geographic factors (e.g., climate, geologic setting) and landscape setting (hydrogeomorphic type) are expected to affect both water quality and biotic communities. A hypothetical example of how geographic factors, landscape setting, and habitat type could be taken into account in establishing a sampling design is presented below for the Prairie Pothole Region.

Hypothetical Case Study: Prairie Pothole Region

The following example illustrates some of the considerations necessary in designing a classification strategy for a given region. The resulting classification could be used for a variety of purposes, e.g., stratification of populations for describing ecological condition, choice of reference wetlands against which to compare impacted or restored sites in local assessments, or derivation of nutrient or biological criteria by wetland class. As this example illustrates, the strategy employed for a given region could easily incorporate elements of several different classification schemes. For example, a combination of ecoregions, hydrogeomorphic wetland classes, Rosgen channel types or water permanence (NWI hydrology modifier), and NWI cover system/class is recommended. In this case, a different set of strata is recommended for different hydrogeomorphic types. Finally, behavior of different wetland classes can vary depending on the period of the wet-dry cycle, so that differences in reference condition should be described over time.

In the Prairie Pothole Region, the main hydrogeomorphic wetland types vary by ecoregion because of the influence of glacial history on the distribution of landforms. For example, the Glaciated Plains ecoregions contain predominantly depressional wetlands that are differentiated from one another by hydroperiod related to position in the landscape and in the groundwater flow path. Wetlands high in the landscape typically are fed by snowmelt or direct precipitation, are groundwater recharge sites, and have hydrology that is temporary or seasonal in nature. Temporary wetlands will typically have a wet meadow and emergent vegetation zone, whereas seasonal wetlands may have some shallow standing water as well as emergent vegetation and wet meadow zones. Wetlands further down the landscape gradient will have a longer hydroperiod and receive more groundwater discharge. Semipermanent wetlands will have the three habitat zones described above, while permanent wetlands will be saline due to groundwater inputs and high evapotranspiration rates and have very little or no emergent vegetation along the shore (with very low diversity).

Macroinvertebrate community structure will be influenced by both hydroperiod and vegetative structure. Predator taxa (both large-bodied invertebrates and tiger salamander larvae) will be more dominant in systems with longer hydroperiods (e.g., semipermanent or permanent wetlands) and should have an influence on lower trophic level structure as well. Waterfowl use also differs among wetland basins with different hydroperiods, although many waterfowl will use a variety of wetland types over the course of the season.

Nutrients in the water column, particularly phosphorus, will differ between wet and dry years and between vegetative zones. During the wet cycle anoxia may develop, but open-water zones will experience some diurnal fluctuations in dissolved oxygen, with the net result that phosphorus released to the water column is tied up with iron that oxidizes as it diffuses from the sediments. Heavily vegetated zones tend to become anoxic throughout the water column and remain stagnant throughout the diurnal cycle. Phosphorus could also be more available in shallower systems with abundant vegetation because dissolved organic carbon is higher and may serve to keep phosphate-iron-humic complexes in solution. Thus, wetlands may switch from nitrogen limitation during low to average rainfall years to phosphorus limitation during wet years. Thus, reference trophic status will be a combined function of water permanence and vegetative cover, both of which influence redox conditions and nutrient cycling.

A reasonable sampling design for wetlands in the Prairie Pothole Region for both water quality and biological communities would be to first stratify by ecoregion into Northwestern Glaciated Plains, Northern Glaciated Plains, and Red River Valley to take into account differences in landform (and thus wetland density) and the east-to-west gradient in precipitation:evapotranspiration ratio. It is possible that reference condition would be similar across the two glaciated plains ecoregions and that the greatest amount of variation would be explained by differences in hydroperiod among wetlands; this could be assessed after sampling was complete. Within the Prairie Pothole Region, there are two predominant hydrogeomorphic wetland classes, depressional wetlands and riverine wetlands. Within the HGM class of depressional wetlands, wetland basins could be stratified according to hydroperiod (based on NWI hydrologic modifier), e.g., temporary vs. seasonal vs. semipermanent vs. permanent. This could be done in an automated fashion using NWI maps by selecting basins based on the polygon within the basin, with a hydrologic modifier denoting the longest hydroperiod. It is possible that reference condition might be similar enough between temporary and seasonal wetlands, or between seasonal and semipermanent wetlands, so that these hydrologic types could be combined, but it is also likely that the degree of difference would depend on the status of the wet-dry cycle, so these differences should be examined empirically over a wet-dry cycle before combining types. For depressional basins, it is likely that variance in reference condition would be minimized if sampling were further stratified (or restricted) by cover system/class (palustrine open water vs. palustrine emergent), and within the palustrine emergent class by the presence or absence of standing water (shallow emergent vegetation zone vs. wet meadow zone). The latter strategy would allow potentially useful comparisons to be made across hydrologic types within vegetative class/zone.

Within riverine systems of the Prairie Pothole Region, wetlands can be divided into three NWI subsystems: Lower Perennial (with aquatic bed, emergent vegetation, and unconsolidated shore subclasses), Upper Perennial (aquatic bed and unconsolidated shore), and Intermittent (streambed only). Reference condition and responses of vegetation in Lower and Upper Perennial subclasses to hydrologic impacts such as dams and withdrawals for irrigation can be expected to differ among channel types. For example, braided and meandering systems respond differently to climate change and hydrologic disturbance (Johnson 1998); thus main Rosgen channel type could be used as an intermediate strata between NWI system and NWI subclass.

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Appendix A-1. Cross-walk between Anderson and Cowardin classification schemes per Robert Brooks (Pennsylvania State University). Coding consistent with Anderson et al. 1976, and Cowardin et al. 1979.

Type	Anderson et al. 1976	Cowardin et al. 1979
2. Aquatic Cover		
1. Palustrine	61x	P
1. Open water (< 8ha)		POW
2. Aquatic bed	613	PAB
3. Emergent	616	PEM
4. Scrub/Shrub	617	PSS
1. Mainly Evergreen	6182	PFO2,3,4,7
2. Mainly Deciduous	6181	PFO1,6
3. Mixed	--	PFO#/#
5. Forested	618	PFO
1. Mainly Evergreen	6182	PFO2,3,4,7
2. Mainly Deciduous	6181	PFO1,6
3. Mixed	--	PFO#/#
2. Lacustrine (> 8ha)	6xx	L
1. Open water		LOW
1. Limnetic	62x	L1
1. Aquatic bed	623	L1AB
2. Unconsol=d bottom	622	L1UB
2. Littoral	63x	L2
1. Aquatic bed	633	L2AB
2. Emergent	636	L2EM
3. Unconsolidated bottom/shore	632/635	L2UB/US
3. Riverine*	65x, 66x, 67x	R
1. Open water	650/660	ROW
2. Aquatic bed	6x3	RxAB
3. Emergent	6x6	RxEM
4. Unconsolidated bottom	6x2	RxUB/US
* Riverine includes all headwater streams and mainstem rivers, with an associated narrow band of wetland.		
4. Estuarine	68x, 69x	E
1. Open water	68x, 69x	EOW
1. Subtidal	68x	E1
2. Intertidal	69x	E2
2. Aquatic bed	683, 691	ExAB
3. Emergent	696	ExEM
4. Scrub/shrub	697	ExSS
5. Unconsolidated bottom	682, 695	ExUB/US
5. Marine	70x	M
1. Open water		MOW
1. Subtidal		M1
2. Intertidal		M2
2. Aquatic bed		MxAB
3. Rocky shore		M2RS
4. Unconsolidated bottom/shore		MxUB/US

Appendix A-2: Cross-walk between Circular 39 wetland types (Shaw and Fredine 1959) and Cowardin classification system, adapted from Cowardin et al. 1979

Circular 39 wetland class	Cowardin Classification System		
	Classes	Water Regimes	Water Chemistry
Type l-Seasonally flooded basins or flats	Emergent Wetland Forested Wetland	Temporarily Flooded Intermittently Flooded	Fresh Mixosaline
Type 2-Inland fresh meadows	Emergent Wetland	Saturated	Fresh Mixosaline
Type 3-Inland shallow fresh marshes	Emergent Wetland	Semipermanently Flooded Seasonally Flooded	Fresh Mixosaline
Type 4-Inland deep fresh marshes	Emergent Wetland Aquatic Bed	Permanently Flooded Intermittently Exposed Semipermanently Flooded	Fresh Mixosaline
Type 5 - Inland open fresh water	Aquatic Bed Unconsolidated Bottom	Permanently Flooded Intermittently exposed	Fresh Mixosaline
Type 6 - Shrub swamps	Scrub-shrub Wetland	All Nontidal Regimes except Permanently Flooded	Fresh
Type 7- Wooded swamps	Forested Wetland	All Nontidal Regimes except Permanently Flooded	Fresh
Type 8 - Bogs	Scrub-shrub WetlandForested WetlandMoss-lichen Wetland	Saturated	Fresh (acid only)
Type 9 - Inland saline flats	Unconsolidated Shore	Seasonally flooded Temporarily flooded Intermittently Flooded	Eusaline Hypersaline
Type 10 - Inland saline marshes	Emergent Wetland	Semipermanently Flooded Seasonally Flooded	Eusaline
Type 11 - Inland open saline water	Unconsolidated Bottom	Permanently Flooded Intermittently Exposed	Eusaline
Type 12 - Coastal shallow fresh marshes	Emergent Wetland	Regularly Flooded Irregularly Flooded Semipermanently Flooded - tidal	Mixosaline Fresh
Type 13 - Coastal deep fresh marshes	Emergent Wetland	Regularly Flooded Semipermanently Flooded - tidal	Mixosaline Fresh
Type 14 -Coastal open fresh water	Aquatic Bed Unconsolidated Bottom	Subtidal Permanently flooded tidal	Mixosaline Fresh
Type 15 - Coastal salt flats	Unconsolidated Shore	Regularly Flooded Irregularly Flooded	Hyperhaline Euhaline
Type 16 - Coastal salt meadows	Emergent Wetland	Irregularly Flooded	Euhaline Mixohaline
Type 17 - Irregularly flooded salt marshes	Emergent Wetland	Irregularly Flooded	Euhaline Mixohaline
Type 18 - Regularly flooded salt marshes	Emergent Wetland	Regularly Flooded	Euhaline Mixohaline
Type 19 - Sounds and bays	Unconsolidated BottomAquatic BedUnconsolidated Shore	Subtidal Irregularly Exposed Regularly Flooded Irregularly Flooded	Euhaline Mixohaline
Type 20 - Mangrove swamps	Scrub-shrub WetlandForested Wetland	Irregularly Exposed Regularly Flooded Irregularly Flooded	Hyperhaline Euhaline MixohalineFresh

Appendix B. Sources of GIS coverages and imagery for mapping and classifying wetlands

Category	Source	Web site
Wetland and hydrography coverages		
Cowardin et al. (1979) classification	National Wetland Inventory	http://www.nwi.fws.gov/
	Wisconsin Wetland Inventory	http://www.dnr.state.wi.us/org/at/et/geo/guide_2e /app_g/custodia/wwi_1.htm
	Minnesota modified NWI (contains Circ. 39 classes)	http://lucy.lmic.state.mn.us/metadata/nwi.html
	Ohio Wetland Inventory	http://www.dnr.state.oh.us/odnr/relm/resanalysis/ owidoc.html
	S. California Coastal Wetlands Inventory	http://ceres.ca.gov/wetlands/geo_info/so_cal.html Ferren et al., 1996
Great Lakes coastal wetlands	Herdendorf et al., 1981	N/A
Hydrography (1:100,000)	USGS - National Hydrography Dataset (NHD)	http://nhd.usgs.gov/
General land-cover (including wetlands)		
Aerial photos	SCS county offices	
Aerial photos	USGS digital orthophotoquads (DOQs)	www.terraserver.com
Satellite imagery	MultiResolution Landscape Characterization (MRLC)	http://edcwww.cr.usgs.gov/programs/lccp/ natllandcover.html
	GAP habitat cover types	http://www.gap.uidaho.edu/gap/
Natural Heritage programs	Individual States	
Unclassified satellite imagery	USGS	http://earthexplorer.usgs.gov
Geographic regions		
Ecoregions	EPA (Omernik 1987)	http://water.usgs.gov/GIS/metadata/usgswrd/ ecoregion.html
Ecological Units	USFS (Keys et al 1995)	
Hydrologic Units	USGS HUCs	http://water.usgs.gov/GIS/huc.html
Watershed boundaries	Individual States/NRCS	http://www.ftw.nrcs.usda.gov/HUC/huc_ download.html
Historic or potential wetland coverage		
Soils	STATSGO	http://water.usgs.gov/lookup/getspatial?muidhttp:/ /water.usgs.gov/lookup/getspatial?ussoils
	County soil surveys - SSURGO	http://www.ftw.nrcs.usda.gov/ssur_data.html
Surficial geology	USGSState geological surveys	http://water.usgs.gov/lookup/getspatial?ofr99-77 _geol75m
Climate	NOAA	http://water.usgs.gov/lookup/getspatial?climate_ divhttp://www.ocs.orst.edu/prism/prism_new.html
Digital elevation models (DEMs)	USGS National Elevation Database (NED)	http://edcnts12.cr.usgs.gov/ned

Appendix C. Case studies applying wetland classification schemes for indicator development or status assessment

Study (location)	Wetland type	Classification Criteria	Success
Cole et al., 1997 (PA)	Riparian wetlands in PA	HGM subclasses	Sign. differences in hydrological attributes among subclasses
Gernes, 1999 (MN)	Riparian wetlands in St. Croix R. Basin	HGM subclasses	Not yet validated
Michigan Natural Features Inventory 1997 (Great Lakes)	Great Lakes coastal wetlands	Great LakeHGM subclasses	Veg. associations distinguished through TWINSPAN by climate regime (N v. S), soil pH, connectivity to lake, and human disturbance
Apfelbeck, 1999 (MT)	All wetland types w standing water in at least one season	Ecoregion Hydrogeomorphic subclass[a]	TWINSPAN, DCCA on diatoms and macroinvertebrates showed good agreement overall[b]
Fennessey et al. (OH)http://www.epa.gov/owow/wetlands/bawwg/case/oh1.html	Riparian wetlands	Ecoregions Hydrogeomorphic classes Watersheds	No definitive comparisons
Galatowitsch et al., 2000 (MN)	Depressional, riparian, littoral, and wet meadows	Ecoregion sections[c] Geomorphic class[d]	No comparisons made across ecoregions or classes
Wilcox et al., 2000 (WI, MI)	Great Lakes coastal wetlands	Great Lake Hydrogeomorphic subclass	No test of alternate classification schemes
Detenbeck, 1994 (MN)	All wetland types	Hydrogeomorphic subclass	Sign. differences in nutrient levels demonstrated by water depth, closed vs. open basins, confirmed by change following disturbance

[a] Headwater wetlands, *riparian* wetlands, open lake wetlands, closed basin wetlands.

[b] Diatom assemblages indistinguishable for *riparian*, open lakes, and closed basin systems; New classes identified based on water chemistry and water permanence- ephemeral, saline, closed basin-recharge, closed basin-surface water, closed basin-alkaline.

[c] MWCP 1997, Ecological Classification System for Minnesota.

[d] Defined by combination of landscape position (depression, *floodplain*, *littoral* zone, sedge meadows + wet prairies), associated river size, and associated lake water chemistry (calcareous vs. noncalcareous).

Glossary

Anderson's classification system A hierarchical classification system for land-use/land-cover derived from remote sensing imagery developed by the U.S. Geological Survey (Anderson et al. 1976).

Channel gradient The slope of the main channel of a stream, typically expressed in change in elevation (feet) per mile.

Channel units "Subdivisions of a stream reach that represent specific habitat and micro-habitat units that are quite uniform in their morphologic and hydraulic properties" (Maxwell et al. 1995)

Classification The process of assigning units to categories by similarity of attributes, generally with a purpose of reducing variation within classes.

Cluster analysis An exploratory multivariate statistical technique that groups similar entities in an hierarchical structure.

Delphi approach A means to record best professional judgments through a consensus-building approach.

Depressional wetland A hydrogeomorphic wetland type located in topographic depressions where surface water can accumulate.

Detrended canonical correlation analysis A multivariate technique for relating multiple explanatory variables to multiple response variables (e.g. species abundances).

Digital elevation models A grid-based geo-referenced representation of relative elevation across a landscape in electronic form.

Discriminant function analysis A multivariate statistical technique that allows one to determine what combination of explanatory variables best predicts the separation among classes of observations.

Ecological units Mapped units that are delineated based on similarity in climate, landform, geomorphology, geology, soils, hydrology, potential vegetation, and water.

Ecoregion A geographic unit derived through comparison of climate, climax vegetation, land-use, and soils maps. Several different classification schemes have been developed, including those by Omernik 1997 and Bailey 1976.

Emergent vegetation "Erect, rooted herbaceous angiosperms that may be temporarily to permanently flooded at the base but do not tolerate prolonged inundation of the entire plant; e.g., bulrushes (Scirpus spp.), saltmarsh cordgrass" (Cowardin et al. 1979).

Environmentally based classification In this chapter, an environmentally based classification scheme does not rely on geographically based similarities, but classifies units based on their attributes (e.g., watershed land-cover classes) independent of geographic adjacency.

Estuarine System "Deepwater tidal habitats and adjacent tidal wetlands that are usually semienclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land." (Cowardin et al. 1979) The Coastal Zone Management Act of 1972 includes estuarine-type coastal wetlands in the Great Lakes in this definition, but Cowardin's system of classification does not.

Euhaline Systems with salinity of 30.0-40 ppt, derived primarily from ocean salts.

Floodplain "The lowland that borders a stream or river, usually dry but subject to flooding." (NDWP Water Words Dictionary, http://www.state.nv.us/cnr/ndwp/dict-1/waterwds.htm)

Fringe wetlands Wetlands that occur along or near the edge of a large body of water (oceanic or large lake) such that the water surface elevation of the wetland is influenced by tides and seiche activity of the adjacent water body.

Functional assessment A process for estimating the functions or processes occurring in a wetland such as nutrient cycling, food chain support, and water retention.

Geographic information system (GIS) A computerized information system that can input, store, manipulate, analyze, and display geographically referenced data to support decision-making processes. (NDWP Water Words Dictionary)

Geographically based classification An approach for delineating units of land based on similarity of adjacent lands with respect to attributes such as climate, natural potential vegetation, soils, and landforms.

Geomorphology The origins and changing structure and form of the earth's land surfaces

Hydraulic conductivity The rate at which water can move through an aquifer or other permeable medium (NDWP Water Words Dictionary)

Hydrodynamics Branch of science that deals with the dynamics of fluids, especially incompressible fluids, in motion (NDWP Water Words Dictionary)

Hydrogeomorphic Land form characterized by a specific origin, geomorphic setting, water source, and hydrodynamic (NDWP Water Words Dictionary)

Hydrogeomorphic Assessment Approach A process of evaluating wetland functions by comparing site profiles with those of reference wetlands in a similar hydrogeomorphic class.

Hydrography Description and mapping of oceans, lakes, and rivers. (NDWP Water Words Dictionary)

Interfluve An area of relatively unchannelized upland between adjacent streams flowing in approximately the same direction.

Lacustrine "Includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, persistent emergents, emergent mosses or lichens with greater than 30% areal coverage; and (3) total area exceeds 8 ha (20 acres). Similar wetland and deepwater habitats totaling less than 8 ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part of the basin exceeds 2 m (6.6 feet) at low water...may be tidal or nontidal, but ocean-derived salinity is always less than 0.5%" (Cowardin et al. 1979).

Landform A discernible natural landscape that exists as a result of wind, water or geological activity, such as a plateau, plain, basin, mountain, etc. (NDWP Water Words Dictionary)

Lentic Characterized by standing water, e.g., ponds and lakes.

Limnetic The open water of a body of fresh water.

Littoral Region along the shore of a non-flowing body of water.

Lotic Characterized by flowing water, e.g., streams and rivers.

Mesosaline Waters with salinity of 5 to 18%, due to land-derived salts.

Mineral soil flats Level wetland landform with predominantly mineral soils

Mineralization The process of breaking down organic matter to its inorganic constituents

Minerotrophic Receiving water inputs from groundwater, and thus higher in salt content (major ions) and pH than ombrotrophic systems.

Mixohaline Water with salinity of 0.5 to 30%, due to ocean salts.

Multivariate Type of statistics that relates one or more independent (explanatory) variables with multiple dependent (response) variables.

Nonmetric dimensional scaling A nonparametric statistical technique for indirect ordination, e.g., ordering a series of observations along a gradient based on similarity/differences in community composition independent of any potential explanatory variables. Vectors related to potential explanatory variables can be overlaid on NMDS plots to ascertain potential environmental relationships with community gradients.

Nonparametric Referring to a type of statistical approach that does not rely on the assumption that data are distributed according to a normal distribution.

Nutrient ecoregions Level II ecoregions defined by Omernik according to expected similarity in attributes affecting nutrient supply (http://www.epa.gov/OST/standards/ecomap.html)

Ombrotrophic Receiving water inputs predominantly from precipitation rather than groundwater.

Organic soil flats Wetland landforms that are level, expansive, and comprised of predominantly organic soil.

Palustrine "Nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5%. It also includes wetlands lacking such vegetation, but with all of the following four characteristics: (1) area less than 8 ha (20 acres); (2) active wave-formed or bedrock shoreline features lacking; (3) water depth in the deepest part of basin less than 2 m at low water; and (4) salinity due to ocean-derived salts less than 0.5%" (Cowardin et al. 1979).

Peatlands "A type of wetland in which organic matter is produced faster than it is decomposed, resulting in the accumulation of partially decomposed vegetative material called Peat. In some mires peat never accumulates to the point where plants lose contact with water moving through mineral soil. Such mires, dominated by grasslike sedges, are called Fens. In other mires peat becomes so thick that the surface vegetation is insulated from mineral soil. These plants depend on precipitation for both water and nutrients. Such mires, dominated by acid-forming sphagnum moss, are called Bogs." (NDWP Water Words Dictionary)

Persistent emergent vegetation Emergent hydrophytes (water-loving plants) that generally remain standing until the beginning of the next growing season, such as cattails or bulrushes.

Physiography Physical geography

Pocosin Evergreen shrub bog, found on Atlantic coastal plain.

Random-stratified A type of sampling in which the population is first subdivided into predefined classes (strata) based on perceived similarities, and then subsamples are selected randomly (each with an equal chance of selection) from within each class.

Reference wetlands Under the Hydrogeomorphic Assessment approach, "(r)eference wetlands are actual wetland sites that represent the range of variability exhibited by a regional wetland subclass as a result of natural processes and anthropogenic disturbance." (Smith et al. 1995)

Reference condition Under the EPA's Biocriteria program, wetland reference condition is defined as the status of wetland sites either unaltered or least-impaired by anthropogenic disturbance.

Reference domain Under the Hydrogeomorphic Assessment approach, the geographic area from which reference wetlands are selected (Smith et al. 1995)

Riparian "Pertaining to the banks of a river, stream, waterway, or other, typically, flowing body of water as well as to plant and animal communities along such bodies of water. This term is also commonly used for other bodies of water, e.g., ponds, lakes, etc., although Littoral is the more precise term for such stationary bodies of water." (NDWP Water Words Dictionary)

Riverine System "Includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts in excess of 0.5%." (Cowardin et al. 1979)

Riverine wetland A hydrogeomorphic class of wetlands found in floodplains and riparian zones associated with stream or river channels.

Site potential "The highest sustainable functional capacity that can be achieved in a reasonable period of time by a wetland, given disturbance history, land use, or other ecosystem and landscape scale factors that influence function." (See http://www.wes.army.mil/el/wetlands/pdfs/wrpde9.pdf)

Slope wetland A wetland typically formed at a break in slope where groundwater discharges to the surface. Typically there is no standing water.

Stratification The process of separating a population into classes prior to sampling.

Stream reaches A length of channel which is uniform in its discharge depth, area, and slope (NDWP Water Words Dictionary)

Stream order A measure of stream size. First order streams have no tributaries, while second-order streams can only be formed by the union of two first order streams and so on.

Submerged aquatic bed "The Class Aquatic Bed includes wetlands and deepwater habitats dominated by plants that grow principally on or below the surface of the water for most of the growing season in most years." (Cowardin et al. 1979)

Terrace "An old alluvial plain, ordinarily flat or undulating, bordering a river, lake, or the sea. Stream terraces are frequently called second bottoms, as contrasted to flood plains, and are seldom subject to overflow... Also, a Berm or discontinuous segments of a berm, in a valley at some height above the Flood Plain, representing a former abandoned flood plain of the stream." (NDWP Water Words Dictionary)

Trophic status Degree of nutrient enrichment of a water body.

Univariate Type of statistical analysis involving a single dependent (response) variable.

Valley segments "Valley segments stratify the stream network into major functional components that define broad similarities in fluvial processes, sediment transport regimes, and riparian interactions." (Maxwell et al. 1995)

Waters of the United States Waters of the United States include:

a. All waters that are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters that are subject to the ebb and flow of the tide;

b. All interstate waters, including interstate wetlands;

c. All other waters such as interstate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce including any such waters:

1 That are or could be used by interstate or foreign travelers for recreational or other purposes;
2 From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or
3 That are used or could be used for industrial purposes by industries in interstate commerce;

d. All impoundments of waters otherwise defined as waters of the United States under this definition;

e. Tributaries of waters identified in paragraphs (a) through (d) of this definition;

f. The territorial sea; and

g. Wetlands adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (a) through (f) of this definition.

Wetland(s) (1) 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 [EPA, 40 C.F.R.§ 230.3 (t) / USACE, 33 C.F.R. § 328.3 (b)]. (2) 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 the purposes of this classification, wetlands must have one or more of the following three attributes: (a) at least periodically, the land supports predominantly hydrophytes, (b) the substrate is predominantly undrained hydric soil, and (c) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year (Cowardin et al. 1979). (3) The term "wetland," except when such term is part of the term "converted wetland," means land that (a) has a predominance of hydric soils, (b) is inundated or saturated by surface 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 (c) under normal circumstances does support a prevalence of such vegetation. For purposes of this Act and any other Act, this term shall not include lands in Alaska identified as having a high potential for agricultural development which have a predominance of permafrost soils [Food Security Act, 16 U.S.C. 801(a)(16)].

Wetland functions Physical, chemical, or biological processes inherent to wetlands. Functions may or may not be related to wetland "services" or benefits to society.