WETLANDS, Vol. 13, No. 3, September 1993, pp. 185–193

USE OF CREATED WETLAND DELINEATION AND WEIGHTED AVERAGES AS A COMPONENT OF ASSESSMENT

R. B. Atkinson
University Center for Environmental and Hazardous Materials Studies
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0415

J. E. Perry
Wetlands Department
Virginia Institute of Marine Science
Gloucester Point, VA 23062

E. Smith
Department of Statistics
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0439

J. Cairns, Jr.
Department of Biology and
University Center for Environmental and Hazardous Materials Studies
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0415

Abstract: Forested wetland creation for compliance with Section 404 of the Clean Water Act is increasing dramatically throughout the Mid-Atlantic region of the United States. However, no quantitative data are available regarding the effectiveness of past forested wetland creation efforts in this region, and no quantitative assessment techniques for evaluating success have been developed. Created wetlands may lack sufficient time for soil formation; however, colonizing vegetation and hydrology may be considered indicators of existing conditions. Hydrology monitoring is expensive, time-consuming, and highly variable over short time periods. This study was designed to test the hypothesis that one parameter (vegetation) could be used to evaluate early site conditions following wetland creation. We attempt to show the advantages and disadvantages of using vegetation to calculate percentage "wetland" and "upland" as an early monitoring tool. Calculations were made using the 1989 *Federal Manual for Identification and Delineation of Jurisdictional Wetlands*, colonizing vegetation weighted average, site moisture estimates, and comparisons with an adjacent reference wetland. Percentage "wetland" and "upland" estimates were similar whether vegetation alone or vegetation in combination with hydrology was used in calculations. Vegetation colonizing the site may respond to both soil and hydrology and may provide an early indication of conditions within created wetlands. The findings of this study suggest that calculating plot-weighted averages and comparison with pre-impact wetland vegetation (or an adjacent reference wetland) may be a useful component of a monitoring scheme for certain created wetlands.

Key Words: created wetlands, delineation, indicator status, Section 404, weighted average, wetlands.

INTRODUCTION

Section 404 of the 1972 Federal Water Pollution Control Act as amended requires a permit from the U.S. Army Corps of Engineers (Corps) for most activities involving placement of fill material in a wetland. Plans to create a wetland to compensate for wetland losses have become a widely used component of permit applications. Forested wetland creation in Virginia began in 1980 and has rapidly become the preferred method of mitigation. Documentation is sparse, but 20 to 40 ha of forested wetlands have been created by Virginia Department of Transportation (VDOT), which has received the greatest number of permits issued to a single permittee by the Norfolk District of the Corps (Allen-Grimes, pers. comm.). A large number of major highway projects are anticipated within the coastal plain of Virginia. Approximately three-fourths of the state's wetlands are located in this province (Tiner and Finn 1986), and over 400 ha of forested wetlands may be filled as a direct result of highway construction by 1995. In spite of this projected ten-fold increase in total forested wetland creation attempts, no quantitative monitoring study exists in Virginia.

Delineation of naturally occurring wetlands using the *Federal Manual for Identification and Delineation of Jurisdictional Wetlands* (Federal Interagency Committee for Wetland Delineation 1989) ("Federal Manual") uses a three parameter method that includes soil, hydrology, and vegetation. However, the Federal Manual considers newly created wetlands "problem areas" and suggests that hydrology, vegetation, and professional judgment be used to delineate wetlands (Federal Interagency Committee for Wetland Delineation 1989). Freshwater wetland creation techniques usually involve grading of an upland site to ambient water-table elevation, leaving the mineral soil without amendments, planting saplings, allowing natural colonization by herbaceous vegetation, and assuming a successional progression from emergent to forested wetland (Clewell and Lea 1990). Unless amended, created wetland soils are essentially upland mineral soils and may require years to exhibit hydric soil indicators. Created wetland site inspections of hydrologic conditions in Virginia confirmed the presence of a range of freshwater, non-tidal water regimes given by Cowardin et al. (1979); however, many areas within created wetlands are drier than the wetland water regimes listed. Such areas within created wetlands seldom have standing water, are only moist at the surface following precipitation events, and fail to meet the hydrology criterion of the Federal Manual. To allow plot-wise comparison of hydrology and vegetation, a proposed moisture modifier system is presented here and includes wetland and upland hydrology modifiers (Table 1).

Wetland vegetation has colonized the 12 created forested wetlands surveyed in the current study as well as created forested wetlands studied by other researchers (e.g., Butts 1988, Clewell and Lea 1990). However, based on the Federal Manual, the hydrology criterion was not met in several plots that narrowly met the vegetation criterion. To increase sensitivity of the vegetation parameter, a technique using all species found in plots was selected. For direct gradient analysis of vegetation along a single environmental gradient, such as moisture, weighted averages (WA) may be used (Whittaker 1978). Weighted averages have been described as useful for assessing wetland status of some vegetation types along a moisture gradient for wetland delineation under natural conditions (Carter et al. 1988, Wentworth et al. 1988, and Scott et al. 1989). Weighted averages are also used in the "Comprehensive Onsite Determination Method" described in the Federal Manual, where it is referred to as a "prevalence index" and is an optional method for determination of the vegetation parameter. In this study, WA of vegetation colonizing created wetlands was measured and compared to the proposed moisture modifier system.

The purpose of this study was to compare the Federal Manual for wetland delineation, weighted averages and moisture modifiers, and use of an adjacent reference wetland to design an early assessment scheme for created wetlands. Establishing the hydrology criterion in marginal cases is a time-consuming, expensive effort and may not be realistic for agencies, considering the increased area involved. Likewise, soil may not be a useful parameter since soil transformation processes may require years. This study seeks to analyze the response of colonizing vegetation to hydrology in created wetlands to determine the advantages and disadvantages of vegetation as a component of early site monitoring. Weighted averages may enhance the sensitivity of this parameter.

SITE DESCRIPTION

The Wagner Road created wetland site ("Wagner Site") is located at 37° 11′ 44″ north latitude, 77° 20′ 26″ west longitude in Petersburg, Virginia (Figure 1). The 1.53-ha site was created in summer of 1987, and woody saplings (up to 2-m tall) and shrubs from Waynesboro Nurseries, Inc., Waynesboro, Virginia were planted in February 1989. The study area is in the upper coastal plain, between Old Wagner Road and its replacement, Route 795 (New Wagner Road). The site is within Blackwater Swamp headwaters, which has been recommended for state scenic river designation. The previously early successional upland forest was graded to approximately ambient wetland elevations, 37.85 m above sea level. Although permit conditions called for backfill of hydric soil to 30 cm above upland mineral soil, there is no evidence of hydric soil deposition. Surface percent organic matter content in the created wetland ranged from 1.3 to 3.3%, with an average of 1.87% (± 0.74). Organic matter at 0.1 m below surface ranged from 0.9 to 5.2%, with an average of 1.90% (± 1.63). An adjacent, natural forested wetland was used as a reference site following selection criteria described in Abbruzzese et al. (1987). All dominant species in the reference site strata were either obligate wetland or facultative wetland species. A middle-aged stand of *Fraxinus pennsylvanica* Marshall, *Nyssa sylvatica* var. *biflora* (Walter) Sargent, and *Taxodium distichum* (L.) Richard formed the dominant canopy in the reference site. The subcanopy stratum

Table 1. Water regime modifiers for mean growing season surface moisture from Cowardin et al. (1979) and the proposed system.

	Proposed Soil Moisture Modifiers	
Cowardin Modifiers	Modifier	Moisture Range and Description
Permanently flooded, intermittently exposed,	8	standing water >20 cm deep, 100% coverage
semipermanently flooded, seasonally	7	standing water 11–20 cm deep, 100% coverage
flooded	6	standing water (all depths) 50% to 100% coverage
Saturated, intermittently flooded	5	soil saturated (>field capacity) or standing water (all depths) 0–50% coverage
Temporarily flooded, intermittently flooded	4	soil very moist, near field capacity
Not wetland	3	soil dry to moist, below field capacity
	2	soil dry
	1	soil very dry, often blocky

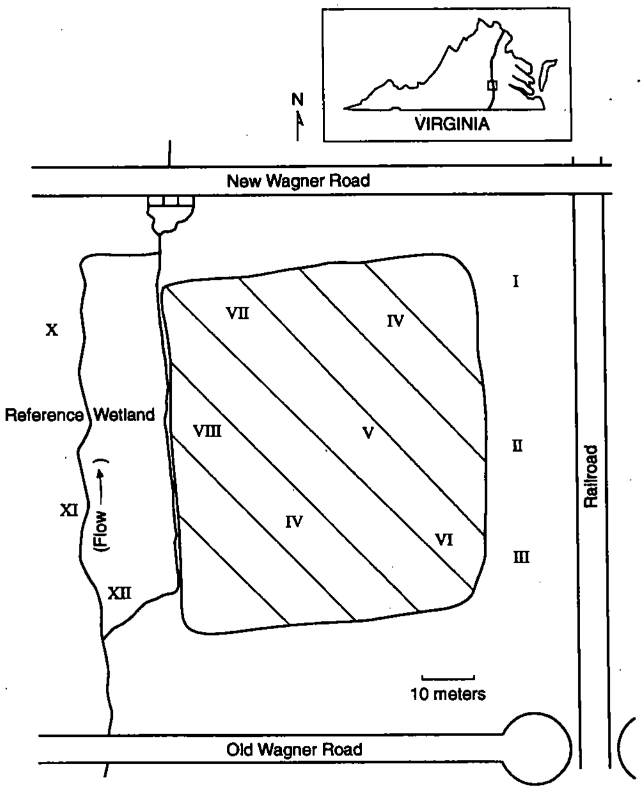

Figure 1. Location of the Wagner Road created-wetland study site in Petersburg, Virginia. Roman numerals are well locations.

was dominated by *Alnus rugosa* (Du Ruo) Sprengel, *Cephalanthus occidentalis* L., *Ilex verticillata* (L.) Gray, and *Sambucus canadensis* (L.). Dominant species in the herb stratum included *Boehmeria cylindrica* (L.) Swartz, *Impatiens capensis* Meerb., *Leersia oryzoides* (L.) Swartz, and *Murdannia keisak* (Hassk.) Hand.-Mazz. No obligate upland or facultative upland species were found in the reference area. One facultative species, *Aster vimineus*, was present. Organic matter content at the surface and at 0.1 m below the surface of the reference site averaged 4.67% (± 0.92) and 2.40 (± 0.66), respectively. Water-table readings in the created site and reference site were taken from nine pvc pipe wells arranged in a stratified random design. Created site (19.05 cm ± 7.89) and reference site (21.40 cm ± 7.60) depth to water table were not significantly different at the 0.05 level. However, three of six created wetland wells averaged significantly greater depth to water table than the mean for reference wetland wells. Mean standard deviation in depth to water table was greater within individual created wetland wells (± 19.23) than reference wetland wells (± 16.42). The water regime modifier for the reference wetland is "seasonally flooded" (Cowardin et al. 1979). c None of the reference area became drier than "moist" (moisture modifier = 4, Table 1) during the 1989 growing season.

MATERIALS AND METHODS

A modified plot sampling technique of the Federal Manual "Comprehesive Onsite Determination Method" was performed. Permanent sampling locations were established using a stratified random sampling technique with 106 1-m² plots along seven parallel transects in the created wetland and 76 plots along two transects in the reference wetland. Vegetation was sampled monthly from May through September, 1989 and again in September, 1990. Vegetation was identified using several vascular plant keys and nomenclature follows U.S. Department of Agriculture (1982). Classification of species into indicator status categories was accomplished using the *National List of Plant Species that Occur in Wetlands: National Summary* (Reed 1988) (Table 2). The hydrophytic species criterion was met when the prevalence index <3.0 based on September, 1990 vegetation data (Federal Interagency Committee for Wetland Delineation 1989). Modified importance values for each species were calculated as the sum of relative cover and relative frequency (Daubenmire 1959), but only relative cover was used in WA calculations (Jongman et al. 1987).

Relative cover estimates and indicator status of each species in each plot were used to calculate a WA for

Table 2. Indicator categories, probability ranges, and indicator index values for vegetative species occurrence in wetlands (Reed 1988).

Indicator Category	Wetland Frequency	Indicator Index
Obligate wetland	>99%	1
Facultative wetland	67–99%	2
Facultative	34–66%	3
Facultative upland	1–33%	4
Obligate upland	<1%	5

Table 3. Mean weighted average, percent of all plots in the site, and mean moisture for each weighted average range.

	WA		Percent	Moisture	
WA Range	Mean	SD	of Site	Mean	SD
Unvegetated	—	—	1.89	2.30	0.10
>3.00	3.28	0.01	1.89	2.30	0.30
2.5–2.99	2.72	0.15	12.26	2.54	0.51
2.0–2.49	2.16	0.12	19.81	2.69	0.52
1.5–1.99	1.78	0.14	31.13	3.91	0.86
1.0–1.49	1.20	0.15	33.02	5.48	0.61

each plot (Wentworth et al. 1988), also termed community index (Scott et al. 1989), using the following formula (Jongman et al. 1987):

$$WA = (y_1u_1 + y_2u_2 + \ldots + y_mu_m)/100$$

where $y_1, y_2, \ldots, y_m$ are the relative cover estimates for each species in the plot, and $u_1, u_2, \ldots, u_m$ are the indicator values of each species.

Since indicator categories range from 1 to 5, plot indicator status does also. Thus, a plot composed of all obligate wetland species would have a status of 1; a plot of all obligate upland species would have a status of 5. The aerial extent of each created wetland that falls within each 0.5 WA status range was then calculated as a percentage of all plots in the created wetland (Table 3).

Hydrology was derived from monitored well data and a proposed moisture modifier system. Twelve 5.1-cm pvc pipe wells (0.025-cm slot width) were hand-augered and penetrated approximately 1 m. Wells were sealed to prevent vertical infiltration, surveyed, and sampled once per week during April through September, 1989. In order to facilitate hydrologic estimation at all 106 plots, a semi-quantitative range of moisture modifiers was produced and related to a list of non-tidal wetland water regimes given in Cowardin et al. (1979) (Table 1). Qualitative estimates of surface moisture content were made at each quadrat for the five times vegetative cover estimates were made in 1989. Mean moisture content was calculated per plot. Plot and well locations and elevations were surveyed using a laser light level. Mean moisture content per plot was interpolated on maps in order to relate well data. Climatological data for 1989 and 1990 growing seasons were provided by the Virginia Climatology Office, Charlottesville, Virginia.

Soil samples (0.5 l) were collected and pvc pipe wells installed at 12 locations established using a stratified random design. Of the 12 locations, three were in an adjacent upland oak-hickory forest, three were in the reference wetland, and six were in the created wetland. Soil samples were weighed, dried, and reweighed for bulk density and volumetric water content estimates. Organic matter determinations were performed by taking ash-free dry weights of subsamples. Field indicators of hydric soil, including gleization, mottling, low chroma, and dark vertical streaking, were missing in all created wetland and adjacent upland samples but were present in all reference wetland samples. The Federal Manual section "Problem Areas," which includes "newly created wetlands" or "man-made wetlands," states that these wetlands "will have indicators of wetland hydrology and hydrophytic vegetation. But the area may lack typical field characteristics of hydric soils. . ." Therefore, both hydrology and vegetation criteria were used to determine the status of each plot as either "wetland" or "upland."

RESULTS

There were 33 species identified in the 106 plots at Wagner Road in 1989 compared to 57 species in 1990 (Table 4). However, immaturity and the presence of only vegetative organs may have limited identification of species during the second growing season in 1989. Therefore, only 1990 vegetation data were used for WA calculations. Maximum vegetative cover attained by monthly sampling in 1989 occurred in August, and mean percent cover per plot was 25.33% (± 14.80) but was not significantly different from September, 1989 (23.44% ± 14.86). Average raw cover per plot in September, 1990 was significantly greater, 66.09% (± 36.41). Average number of species per plot (5.57 ± 2.58) was the same in August and September, 1989. Number of species per plot in September, 1990 was 8.33 (± 3.63). In 1989, obligate and facultative wetland categories had the highest number of species (13 each) and increased to 21 obligate wetland and 25 facultative wetland species in 1990. Facultative species increased from two in 1989 to five in 1990. Three facultative upland species were found in 1989, and three were found in 1990. Obligate upland species totaled two in 1989 and three in 1990. Species of highest importance values in 1990 were both facultative wetland species

Table 4. Indicator status (IS) and importance values (IV) for herbaceous vascular plant species within the Wagner created wetland and reference wetland as of September, 1990. (* represents species present but not in transects.)

Species	IS	Created IV	Reference IV
Agalinis purpurea (L.) Pennell	2	8.01	
Ambrosia artemisiifolia L.	4	12.02	
Asclepias incarnata L.	1		*
Aster vimineus Lam.	3		2.42
Bidens frondosa L.	2	21.14	
B. laevis (L.) B.S.P.	1	9.88	*
B. polylepis Blake	2	56.65	*
Campsis radicans (L.) Seem.	3	3.91	
Carex crinita Lam.	1		11.41
C. gigantica Rudge	1		2.66
C. lurida Whalenb.	1		4.54
C. scoparia Schkuhr ex Willd.	2	1.91	
Cassia fasciculata Michx.	4	14.29	
Cephalanthus occidentalis L.	1	1.89	
Cyperus erythrorhizos Muhl.	2	2.87	
C. esculentus L.	2	1.90	
C. polystachyos Rottb.	2	1.90	
C. pseudovegetus Steud.	2	22.13	
C. strigosus L.	2	7.73	
Dichanthelium scoparium (Lam.) Gould	2	21.68	2.42
Digitaria ischaemum (Schreber) Schreber ex Muhl.	5	11.61	
Diodia teres Walter	5	22.39	
D. virginiana L.	2	20.81	
Echinochloa muricata (Beauv.) Fernald	2	86.59	
Eclipta alba (L.) Hassk.	3	11.43	
Eleocharis fallax Weatherby	1	66.03	
E. obtusa (Willd.) J. A. Schultes	1	58.06	
Eupatorium hyssopifolium L.	5	1.97	
Fimbristylis autumnalis (L.) R. & S.	2	10.49	
Galium obtusum Bigel.	2	10.50	1.98
Hypericum canadense L.	2	7.77	
Impatiens capensis Meerb.	2		19.11
Juncus acuminatus Michx.	1	17.91	
J. canadensis J. Gay	1	6.87	
J. effusus L.	2	24.16	1.43
J. scirpoides Lam.	2	5.81	
J. tenuis Willd.	3	7.75	
Leersia oryzoides (L.) Swartz	1	20.74	26.75
Lemna minor L.	1		1.49
Lespedeza stipulacea Maxim.	4	6.06	
Lindernia dubia (L.) Pennell	1	11.74	
Lobelia cardinalis L.	2	2.87	8.71
Ludwigia alternifolia L.	2	14.89	*
L. linearis Walter	1	6.04	
L. palustris (L.) Elliott	1	32.63	*
Lycopus virginicus L.	1	2.85	3.97
Mikania scandens (L.) Willd.	2	3.95	*
Murdannia kaisak (Hassk.) Hand.-Mazz.	1	18.03	51.31

Table 4. Continued.

Species	IS	Created IV	Reference IV
Panicum dichotomiflorum Michx.	2	78.72	*
P. rigidulum Bosc ex Nees	2	10.11	
P. verrucosum Muhl.	2	75.22	15.93
Paspalum dilatatum Poiret	3	3.96	
P. floridanum Michx.	2	2.98	
P. laeve Michx.	3	34.32	
Pilea pumila (L.) Gray	2		0.94
Polygonum punctatum Elliott	1	29.50	1.98
P. sagittatum L.	1		*
Proserpinaca palustris L.	1	3.84	1.93
Rhexia mariana L.	1	5.71	
Rhynchospora capitellata Michx. ex Vahl	1	5.78	
R. corniculata (Lam.) Gray	1	32.40	0.94
Rotala ramosior (L.) Koehne	1	1.90	
Saururus cernuus L.	1		*
Scirpus atrovirens Willd.	1	1.90	
S. cyperinus (L.) Kunth	2	5.20	*
Typha latifolia L.	1	2.96	
Vallisneria americana Michx.	1	5.22	

including *Echinochloa muricata* (86.59) and *Panicum dichotomiflorum* (78.72) (Table 4).

For within-site comparison, created wetland vegetation at the Wagner Site was treated as two populations of plots, one "wetland" (68 plots) and one "upland" (36 plots). Nearly all obligate wetland species cover (98.8%) occurred in the "wetland" portion of the created wetland. The dominant species in "wetland" plots were usually obligate wetland species and included *Eleocharis fallax* (16 plots), *E. obtusa* (10 plots), and *Ludwigia palustris* (7 plots). Most obligate upland species cover (89.7%) occurred in "upland" plots. One obligate upland species, *Diodia teres*, was found as a dominant at one "upland" plot. Facultative upland species were present in 14 "upland" plots and four "wetland" plots. Facultative wetland species contributed roughly equal cover to both "upland" (42.2%) and "wetland" (57.8%) plots.

The Federal Manual includes "newly created wetlands" under the section "Problem Areas" since these wetlands lack one or more criteria necessary to perform a delineation, most often the soil criterion. Hydric soil indicators were absent at the end of three complete growing seasons (October, 1990); therefore, vegetation and hydrology were used to calculate the percent of the site that was "upland." Based on the Federal Manual, hydrology and/or vegetation criteria were not met in 27.9%, 32.7%, or 33.7% of the plots, using a water-regime modifier of 3.0, 3.5, or 4.0. Federal Manual vegetation criteria were less sensitive than hydrology criteria, and 95.3% of the "upland" plots met the veg-

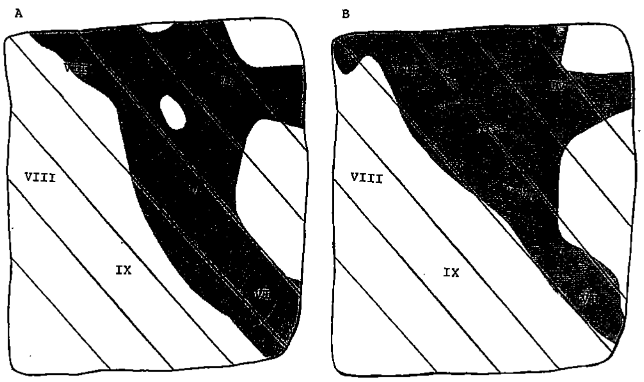

Figure 2. "Upland" and "wetland" portions of the Wagner Road created-wetland study site in Petersburg, Virginia. (A) Shaded area represents "upland" portion of created wetland based on weighted average limit of 2.0. (B) Shaded area represents "upland" portion of created wetland based on moisture modifier limit of 3.5.

Table 5. Percent of site delineated as upland based on moisture modifier and vegetation weighted average (WA).

	Moisture Modifier				
WA	2.5 or Drier	3.0 or Drier	3.5 or Drier	4.0 or Drier	Any Moisture
All*	14.4	33.7	43.3	48.1	100.0
>=1.5	14.4	33.7	43.3	48.1	66.3
>=2.0	11.5	27.9	32.7**	33.7	34.6
>=2.5	6.7	12.5	13.5	14.4	14.4
>=3.0	1.0	1.9	1.9	1.9	1.9

* Denotes entire WA range that includes all plots.
** Denotes percent upland using recommended WA and moisture modifier.

etation criterion (prevalence index <3.0). Two plots (1.5%) were unvegetated and averaged "dry" and were considered "upland" based on the hydrology criterion.

In order to meet the Federal Manual hydrology criterion, the depth to water table must be <15.24 cm (6 inches) for a duration of 1 week or more in somewhat poorly drained mineral soils. Three wells in the "upland" portion of the created wetland measured ground water that was shallower than the 15.24-cm limit on two occasions (June 23 and July 14), and both times were within 24 hours of significant (at least 2.0 cm/24 hours) precipitation events. However, all three wells failed to meet the hydrology criterion for duration of flooding (i.e., greater than or equal to 7 days).

Precipitation totals for May through September, 1989 were 10.6% above normal, and they were 33.9% above normal for the same period in 1990. Moisture estimates indicated considerable variability in surface moisture in the created wetland at any given time. Some plots had standing water throughout the period, while others averaged "dry" to "very dry." Mean moisture estimate per plot for the period from June to September, 1989 was 3.42 (± 2.21), which is "dry/moist" to "moist." A moisture modifier of 3.5 was selected to delineate "upland" versus "wetland" hydrology based on the moisture modifier comparison to the Cowardin et al. (1979) system (Table 1) and also based on the driest mean moisture estimate for the reference wetland. Interpolation with a moisture modifier of 3.5 ("dry to moist" to "moist") defined an area that included only those wells that met the Federal Manual hydrology criterion. The three wells that failed to meet the hydrology criterion were within the area defined as "uplands" based on either WA or a moisture modifier of 3.5 (Figure 2).

Percent "upland" based on WA and moisture modifier ranges was calculated. If both a WA of 2.0 and a moisture modifier of 3.5 are used, 32.7% of the Wagner Site would be "upland," as compared with 34.6% if a WA of 2.0 is used alone (Table 5). Standard deviations were low for moisture modifiers in each WA range (Table 3). Weighted averages were correlated with the proposed moisture modifiers ($r^2 = 0.704$), and maps of the "upland" and "wetland" portions based on either moisture modifier of 3.5 or a WA of 2.0 are similar in location and aerial extent (Figure 2). This suggests that WA alone may be used to delineate initial created wetland "upland"/"wetland" boundaries.

DISCUSSION

Delineation of percent "wetland" and determination of initial success at the Wagner created wetland were assessed in three ways: (1) the recommended method from the Federal Manual "Problem Areas" section, (2) WA and moisture modifiers, and (3) comparison to an adjacent reference area.

Federal Manual

The Federal Manual includes created wetlands as "Problem Areas" that may lack one or more criteria for delineation, most often soils. Hydric soil indicators were absent at the end of three complete growing seasons (October, 1990); therefore, vegetation and hydrology were used to delineate the created wetland. Much of the created wetland exhibited hydrologic characteristics that satisfied the Federal Manual hydrology criterion, but was drier than most of the reference wetland. Likewise, many created wetland plots satisfied the Federal Manual criterion for hydrophytic vegetation, but most reference wetland plots had lower WA.

The Federal Manual hydrology criterion was met less often than was the vegetation criterion. Half of the wells failed to show wetland hydrology, but only two plots failed to meet the vegetation criterion.

WA and Moisture

Wentworth et al. (1988) suggest WA = 2.0 as a limit to the use of vegetation alone to delineate wetlands (i.e., without need of soil or hydrologic data). Use of WA and a soil moisture estimate based on the driest mean moisture estimate of the reference wetland (moisture modifier = 3.5) would cause 32.7% of the site to be "upland." However, WA and moisture estimates were correlated ($r^2 = 0.704$). Furthermore, percent "upland" based solely on use of a WA of 2.0 is 34.6%, compared to percent "upland" calculated using both WA = 2.0 and moisture modifier = 3.5 (32.7%). This close agreement in delineations between vegetation WA and hydrology suggests that WA alone may provide sufficient information for created wetland delineation. We do not recommend use of the moisture modifiers as a substitute for conventional hydrologic measurement techniques. Use of moisture modifiers in this study was a result of the relatively intense vegetation monitoring and the need for equally intense hydrologic monitoring for research purposes.

A WA limit of 2.0 may be selected based on reference site vegetation at Wagner Road. Alternative WA limits may be appropriate for created wetlands designed to replace other wetland types (e.g., those dominated by obligate wetland species (WA = 1–2) or facultative species (WA = 2–3)). However, this study did not examine such wetlands, and colonizing vegetation may well lose predictive ability at higher WA.

Reference Wetland

The vegetative strata of the Wagner created wetland differed greatly from the reference site. Immature or dead plantings and colonizing vegetation yielded a dominant herbaceous strata in the created wetland, compared to a dominant forested strata in the reference wetland. Although similar in WA, created-site "wetland" portions had a higher number of species than the reference wetland. "Upland" portions of the created-site differed from the reference site in both species composition and WA. Species compositional incongruencies among created-site "wetland" portions and the reference wetland may be explained by successional sere differences. However, "upland" portions of the created site may follow a different successional pathway but will require long-term monitoring.

Hydrology in the reference area differed greatly from the created wetland. Although often saturated to the surface and averaging "moist" to "very moist," the reference area seldom had standing water for more than 1 week. Created-site hydrology was more variable, including 20 plots (18.9%) that averaged some standing water. All reference-area moisture modifiers were at least "moist," but 33.7% of the created-wetland plots were drier than "moist" (<4). Elevation, soil organic matter, and absence of climate-moderating swamp canopy may have contributed to created-site hydrologic variability.

Additional Considerations

The presence of five facultative species, three facultative upland species, and three obligate upland species in the created wetland suggest that environmental factors were not severe enough to limit colonization of these species. Soil and/or hydrology characteristics are more than likely responsible. The correlation of vegetation and moisture modifiers seemed to emphasize the importance of hydrology in the system, but causality may also lie in part with soil organic matter content and high bulk density. Created-wetland organic content was roughly half that of the reference wetland. If low organic content in the created-wetland soil renders the substrate relatively sterile, ground-water oxygen levels may not be depleted unless flooding persists. Frequently flooded areas within the created wetland were dominated by obligate wetland species, but conditions elsewhere within the site failed to exclude facultative upland and obligate upland species.

Any measure of percent "wetland" and successional direction must be based on soil, hydrology, and/or vegetation. Scott et al. (1989) found vegetation WA highly correlated with soil conditions in natural wetlands. Soil characteristics in created wetlands considered in this study were more similar to those of uplands than wetlands. Most of the created wetland was characterized by a chroma greater than 2, organic matter of approximately 3%, high bulk density, and low volumetric water content. Considerable time may be required for hydric soil indicators to develop, which limits the role for soil in early delineation of created wetlands.

Like soil, hydrology may not be a suitable parameter for assessment. Historical hydrologic regimes of filled wetlands are usually not known, and adjacent reference-wetland hydrology may be altered by either highway construction or the creation of a wetland "onsite." This complicates comparisons between the original wetland and the wetland created to replace it. Further, hydrologic regimes are typically variable over weeks, seasons, and years and may be expensive to quantify.

Vegetation assessment may not be subject to the drawbacks associated with soil or hydrology monitoring. Vegetation typically colonizes created wetlands in the first growing season following excavation. One visit during peak growing season (July–September) may provide the necessary field data, but it should be noted that significant variation in species composition, and perhaps WA, can occur at different times during a growing season.

Vegetation may be less variable than hydrology and may respond to both soil and hydrologic conditions; thus, it may reflect both soil and hydrologic conditions. Therefore, vegetation may determine what portion of a created wetland is likely to become wetland. However, the early species composition of a created wetland may be a result of early colonization dynamics that may be a poor predictor of subsequent species assemblages. Complete replacement of impacted wetland functions and values will require soil development, appropriate hydrology, and similar vegetative characteristics, which may not occur for decades, if at all. Given the time needed for succession and time constraints on regulatory agencies, early vegetational characteristics may be the preferred means of quantifying percent "wetland." The accuracy of predictions regarding successional direction is still unknown.

Several factors may affect successional direction in created wetlands. Factors suggesting a more xeric direction include soil and hydrology. Soil factors such as higher bulk density in created wetlands may limit slumping and cause accumulated mineral matter to exert a greater increase in elevation. Low organic matter accompanied by high oxygen levels may be a self-perpetuating problem, since high oxygen levels serve to expedite remobilization of organic matter that might otherwise accumulate in wetland ecosystems with anoxic conditions. Factors tending to encourage development of a wetland community also include soil and hydrology. Created wetlands that are located upstream from fill and box culverts (such as the Wagner Road site) may experience more flooding and sediment accumulation as a result of any damming effect by the fill. Such hydrologic alterations are likely to alter natural processes in adjacent wetlands, which may: (a) alter vegetation, especially herbaceous species composition and (b) render such areas unsuitable for reference sites. Vegetative factors such as propagule transport from adjacent and upstream wetlands during flood events may also encourage wetland community development.

CONCLUSIONS

Based on the Federal Manual, vegetation was marginal and hydrology was insufficient to create wetland conditions in one third of the Wagner created wetland site. Weighted averages have been described as useful for assessing wetland status of some vegetation types along a moisture gradient for wetland delineation under natural conditions (Carter et al. 1988, Wentworth et al. 1988, and Scott et al. 1989). Results of the current study suggest that WA may be useful in early assessment of created wetlands. Calculation of an appropriate WA from pre-impact or reference-wetland sites may provide a suitable parameter for comparison.

This study was designed to test the hypothesis that one wetland parameter (vegetation) may be used as a component of an early assessment scheme. Although not designed to complete an assessment of compensation effectiveness at the Wagner Site, some inferences can be made from the study. It seems likely that insufficient hydrology is present at one third of the site. Precipitation was 10.6% above normal for the period from May through September, 1989, yet nearly one third of the site averaged dry. While we cannot be sure that created wetlands perform wetland functions and values, we can infer that uplands are unlikely to perform most wetland functions and values. Since much of the site lacked vegetative cover at the peak growing season and physiognomic differences may take decades to equilibrate, functions and values related to vegetation may not be performed for at least some time to come, if at all.

While it is tempting to suggest that a 1.5:1 compensation ratio would be appropriate based on the results of this study, it would be unreasonable to do so. Even if two-thirds of the Wagner site is determined to be wetlands, no measure of function is implied by this study. Monitoring of additional sites is needed to determine what compensation ratios are sufficient for structural replacement, and functional replacement needs to be addressed. Based on these uncertainties and the time required for even partial replacement, we recommend strict compliance with National Environmental Policy Act guidelines and use of compensation only as a last resort. When losses are unavoidable, creation techniques should incorporate valid experimental design so that continuous improvements can be made.

The monitoring needs of regulatory agencies make vegetation WA an appealing technique. We wish to stress that (1) the predictive ability of this technique regarding succession remains untested, (2) the utility of this approach for drier end wetlands may be severely limited, (3) seasonal changes in vegetation must be considered, and (4) the negative effects of low diversity or exotic and invasive species, if present, are not addressed by this technique.

ACKNOWLEDGMENTS

We express our appreciation for the efforts of Paul Benzing in the field and Dr. Carl Hershner for his shared equipment and expertise. We also acknowledge Dr. Eric Nilsen and Darla Donald for their constructive criticism of the manuscript. We are grateful for the financial support of the Virginia Academy of Science and the Virginia Tech Graduate Student Association.

LITERATURE CITED

Abbruzzese, A. B., A. B. Allen, S. Henderson, and M. E. Ketula. 1987. Selecting sites for comparison with created wetlands. p. 291–297. *In* C. D. A. Rubec and R. P. Overend (eds.) Proceedings, Symposium '87: Wetlands/Peatlands. Edmonton Convention Center, Edmonton, Alberta, Canada.

Butts, M. P. 1988. Status of wetlands creation/mitigation projects in Connecticut. p. 185–187. *In* J. A. Kusler, M. L. Quammen, and G. Brooks (eds.) Proceedings of the National Wetlands Symposium: Mitigation of Impacts and Losses. Association of State Wetland Managers, Berne, NY, USA.

Carter, V., M. K. Garrett, and P. T. Gammon. 1988. Wetland boundary determination in the Great Dismal Swamp using weighted averages. Water Resources Bulletin 24:297–306.

Clewell, A. F. and R. Lea. 1990. Creation and restoration of forested wetlands of the Southeastern United States. p. 195–232. *In* J. A. Kusler and M. E. Kentula (eds.) Wetland Creation and Restoration: The Status of the Science. Environmental Research Laboratory, Corvallis, OR. EPA 600/3-89/038a.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Fish and Wildlife Service, Washington, DC, USA. FWS/OBS-79-31.

Daubenmire, R. F. 1959. Canopy coverage methods of vegetation analysis. Northwest Science 33:43–64.

Federal Interagency Committee for Wetland Delineation. 1989. Federal Manual for Identifying and Delineating Jurisdictional Wetlands. Cooperative technical publication. U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S.D.A. Soil Conservation Service, Washington, DC, USA.

Jongman, R. H., C. J. F. ter Braak, and O. F. R. van Tongeren. 1987. p. 83–86. *In* Data Analysis in Community and Landscape Ecology. Pudoc Wageningen, Weningen, The Netherlands.

Reed, P. B., Jr. 1988. National List of Plant Species That Occur in Wetlands: National Summary. U.S. Fish and Wildlife Service, Washington, DC, USA. Biological Report 88(24).

Scott, M. L., W. L. Slauson, C. A. Segalquist, and G. T. Auble. 1989. Correspondence between vegetation and soils in wetlands and nearby uplands. Wetlands 9:41–60.

Tiner, R. W., Jr. and J. T. Finn. 1986. Status and recent trends in five Mid-Atlantic States: Delaware, Maryland, Pennsylvania, Virginia, and West Virginia. U.S. Fish and Wildlife Service, Region 5, National Wetlands Inventory Project, Newton Corner, MA and U.S. Environmental Protection Agency, Region III, Philadelphia, PA. Cooperative publication.

U.S. Department of Agriculture. 1982. National List of Scientific Plant Names, Vol. 1, U.S. Soil Conservation Service, Washington, DC, USA.

Wentworth, T. R., G. P. Johnson, and R. L. Kologiski. 1988. Designation of wetlands by weighted averages of vegetation data: a preliminary evaluation. Water Resources Bulletin 24:389–396.

Whittaker, R. H. 1978. Direct gradient analysis. p. 9–50. *In* R. H. Whittaker (ed.) Ordination of Plant Communities. W. Junk, The Hague, The Netherlands.

Manuscript received 31 January 1990; revisions received 19 August 1991 and 7 December 1992; accepted 2 April 1993.