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PROFILE

Using GIS to Identify Functionally Significant Wetlands in the Northeastern United States

PAUL T. CEDFELDT
MARY C. WATZIN*
BRUCE DINGEE RICHARDSON
School of Natural Resources
University of Vermont
Burlington, Vermont 05405, USA

ABSTRACT / Of the several automated wetland assessment methods currently available, none are comprehensive in considering all of the primary functions a wetland can perform. We developed a methodology particularly suited to the Northeastern United States that enumerates spatial predictors of wetland function for three primary wetland functions: flood flow alteration, surface water quality improvement, and wildlife habitat. Predictors were derived from several wetland assessment techniques and directly from the literature on wetland structure and function. The methodology was then automated using a Geographic Information System (GIS). The resulting Automated Assessment Method for Northeastern Wetlands (AMNEW) consists of a suite of eight Arc Macro Language (AML) programs that run in the ARC/INFO GRID module. Using remotely sensed land use information and digital elevation models (DEMs), AMNEW produces three separate grids of wetlands that perform each function. The method was tested on four watersheds in Vermont's Lake Champlain Basin. Results and preliminary verification indicate that the method can successfully identify those wetlands in the Northeastern region that have the potential to be functionally important.

Since the advent of wetland regulation in the 1970s, numerous techniques for assessing wetland functions and values have been developed. Wetland functions can be defined as the physical, chemical, and biological processes occurring in and making up a wetland system (Adamus 1992). Wetland values are a more subjective interpretation of the relative worth of some wetland process or product to people.

Of the many wetland assessment techniques appropriate for use throughout the United States, the Wetland Evaluation Technique (WET) (Adamus and others 1987) is the most widely used and technically comprehensive methodology (Adamus 1992, Brinson 1995, National Research Council 1995, U.S. Army Corps of Engineers 1995). WET considers 11 wetland functions and values and provides several different correlative predictors for each function based on an extensive literature review. A second, more recently developed hydrogeomorphic approach (HGM) (Smith and others 1995) differs from WET in that it classifies wetlands into hydrogeomorphic groups before identifying the functions that each group is capable of performing. The range of functioning for each hydrogeomorphic group is determined by previously identified ''reference wetlands'' that encompass the known variation of each hydrogeomorphic group.

KEY WORDS: Wetlands; Wetland function; Wetland assessment; Geographic Information Systems (GIS); Vermont

*Author to whom all correspondence should be addressed.

Less comprehensive and more regionalized assessment techniques have been developed to address the need for rapid wetland assessment that considers local circumstances. Both the Method for the Comparative Evaluation of Nontidal Wetlands in New Hampshire (NHCE) (Amman and Stone 1991) and the Vermont Wetland Evaluation Form (VTWEF) (Vermont Department of Environmental Conservation 1991) were developed specifically for regional use in New England. Although not as comprehensive as the national methodologies, each pays close attention to regional circumstances.

These methods all rely on time-consuming site visits to evaluate each wetland of concern. This requirement has restricted their use. A more efficient approach to functional assessment could be performed with the aid of a Geographic Information System (GIS) (Lyon and McCarthy 1995). An additional benefit of a GIS-based approach is the objectivity it brings to wetland functional analysis. Once specific predictors are established, every wetland can be considered in an unbiased fashion (Golet and others 1994).

Three common wetland functions, flood flow alteration, surface water quality improvement, and wildlife habitat provision, are common to nearly all assessment methods. From both a societal and ecological standpoint, these are generally regarded as the primary functions that wetlands perform (Robinson 1995). Many predictors of these three major wetland functions have spatial components that could be rapidly analyzed with a GIS.

Several methodologies have already been developed that perform some degree of wetland functional assessment with a GIS. Golet and others (1994) developed a GIS-based assessment tool for freshwater wetland wildlife habitats that considers eight different wetland habitat variables and associated metrics. The North Carolina Coastal Region Evaluation of Wetland Significance, or NC-CREWS method, developed by the North Carolina Department of Environment, Health and Natural Resources (1996), uses GIS to evaluate the hydrologic, water quality, and habitat functions of wetlands in this specific coastal area. NC-CREWS's extremely regional focus, however, limits its application outside coastal North Carolina.

The GIS-based automated assessment methodologies currently available are not nearly as well developed as the many field-oriented wetland assessment methods. Although it would have great value to planners and regulators concerned with advanced identification of wetlands of particular ecological significance, a Northeastern regional GIS screening tool for the most widely recognized wetland functions simply does not exist. The objective of our research was to develop just such a screening tool. Our GIS screening tool uses selected predictors from the field-oriented assessment methods in combination with widely available data sets, such as Digital Elevation Models (DEM) and Landsat Thematic Mapper (TM) satellite imagery to identify wetlands performing flood flow alteration, water quality improvement, and wildlife habitat functions.

Methods

The majority of predictors of wetland function were selected from those contained in WET, HGM, NHCE, and VTWEF. Because the tool is based on a GIS, all predictors selected had to be spatially explicit. We acknowledge that many predictors from the various functional assessment techniques cannot be spatially defined, and these could not be incorporated into this assessment tool. Relevant predictors from existing automated assessment techniques were also incorporated, and some predictors were derived directly from the literature on wetland structure and function. All predictors selected had to meet the following criteria:

1. applicable in the Northeast
2. supported in the literature
3. spatially defined
4. measurable by a GIS using widely available data layers

Predictors selected for the functions of flood flow alteration and surface water quality improvement can be divided into two categories. Opportunity predictors assess whether or not a wetland has the potential to perform a given function. Effectiveness predictors assess the capability of a wetland to actually perform the function being considered (Adamus and others 1991). For a wetland to perform a function effectively, it must first have the opportunity to perform that function; therefore, our methodology first selects those wetlands that have the opportunity to perform these functions. Only those wetlands selected for opportunity are then considered for effectiveness, so the final selected set of wetlands show both opportunity and effectiveness. For the wildlife habitat support function, we assumed that all wetlands have the opportunity to provide wildlife habitat, so all predictors are considered as indicators of effectiveness.

Flood Flow Alteration

Flood flow alteration has been defined as the process by which peak flows from precipitation, runoff, surface flow, and groundwater interflow and discharge are stored in a wetland. Temporary storage of water in wetlands allows flood flow desynchronization to occur, a process by which flood waters are stored in several wetlands, then released more gradually, resulting in a decrease in downstream peak flows (Adamus and others 1991). Four opportunity and three effectiveness predictors were chosen as indicators of a wetland's flood flow alteration capability (Table 1). First and foremost, the relationship between dams and wetlands must be considered. Dams are a common part of the Northeastern landscape, having proliferated on many larger streams and rivers in the first half of the nineteenth century to provide power. Dams disrupt many of an ecosystem's natural connections, and the changes that result are well documented (Petts 1984, Allan 1995). Keeping this in mind, our methodology eliminates from consideration any wetlands that are adjacent to the main river channel immediately downstream of a dam. These downstream wetlands will not have the opportunity to perform natural flood flow desynchronization because the upstream dam has already performed the function.

Predictor FAOPP1: Upslope wetlands comprise less than 5% of the wetland's watershed. Ignoring the wetland of concern (WOC), other wetlands at higher elevations in the WOC's watershed are a minor component of the landscape. The rationale for this predictor is that the WOC's opportunity to perform flood flow alteration

Table 1. AMNEW predictors of wetland function

Flood flow alteration function	
FAOPP1	Upslope wetlands comprise less than 5% of the wetland's watershed.
FAOPP2	Wetland area is less than 20% of watershed area.
FAOPP3	The majority (>50%) of the wetland watershed is made up of impervious surfaces.
FAOPP4	Most of the soil (>80%) of the wetland's watershed have a very slow infiltration rate (<1.5 mm/hour).
FAEFF1	Wetland is located near an intermittent or first-order stream.
FAEFF2	Wetland area is larger than 81 ha.
FAEFF3	Wetland has no connection to the surface water network.
Surface water quality improvement function	
SWQOPP1	Wetland's watershed contains potential sources of pollutants.
SWQOPP2	All of the following are true: a. a majority of the watershed is not forested or scrub shrub. b. wetland is less than 5% of watershed acreage. c. Upslope wetlands comprise less than 5% of the watershed.
SWQOPP3	Average slope of the wetland's watershed is greater than 10%.
SWQOPP4	Wetland type is riparian.
SWQEFF1	The soil type underlying a wetland is either histosol or frequently flooded mineral soil with both high clay and high organic matter content.
SWQEFF2	Wetland is located near an intermittent or first-order stream.
Wildlife habitat function	
WL1	Wetland size is larger than 100 ha.
WL2	There is at least one wetland of a different type bordering the wetland being considered.
WL3	Wetland type is the least common in relation to all other wetlands in the watershed.
WL4	Wetland is connected to the surface water network.
WL5	Wetland is completely surrounded by a minimum of 100 m of natural vegetation.
WL6	Wetland is hydrologically connected to another wetland within 400 m.
WL7	Presence of a natural vegetation corridor to another wetland within 400 m.

will be reduced if upslope wetlands have already performed this function to a significant degree (Adamus and others 1991). The 5% figure is derived from WET and is supported by research that indicates that wetland losses in watersheds with less than 10% wetlands can have a significant effect on flood flows (Johnston and others 1990).

Predictor FAOPP2: Wetland area is less than 20% of watershed area. The rationale for this predictor is that more runoff will enter a wetland from a large watershed than a small watershed, therefore, a wetland with a proportionately large watershed will have a greater opportunity to store water and desynchronize flood flows (Adamus and others 1991). If wetland size is held constant as watershed size increases, the opportunity for the WOC to perform this function also increases because of the increased runoff amount entering the wetland.

Predictor FAOPP3: The majority (>50%) of the wetland watershed is made up of impervious surfaces. Runoff amounts in a watershed composed primarily of impervious surfaces will be significantly greater than runoff from a vegetated watershed because infiltration and evapotranspiration are prevented or inhibited (Adamus and others 1991). Therefore, a wetland draining a watershed composed primarily of residential or urban land cover types will have the opportunity, by receiving increased runoff, to perform flood flow alteration.

Predictor FAOPP4: Most of the soils (>80%) in the wetland's watershed have a very slow infiltration rate (<1.5 mm/hour). Similar to the justification for the previous two predictors of opportunity, this predictor indicates increased runoff to the WOC. WET defines very slow infiltration rates as less than 0.006 inches per hour. Several Vermont county soil surveys defined ''very slow infiltration'' as less than 0.06 inches per hour (1.5 mm/hour), therefore, this value was chosen as a threshold more suited to northeastern soils.

Predictor FAEFF1: Wetland is located near an intermittent or first-order stream. This predictor of flood flow alteration effectiveness is meant to account for a wetland's landscape position by selecting those wetlands located in a watershed's upper reaches. The Strahler (1957) stream order method was used to assign order for this and all other predictors that incorporate stream order. Headwater wetlands will desynchronize flood flows more than wetlands located in the lower reaches of the watershed. Although wetlands located near higher-order streams can effectively store flood water (Ogawa and Male 1983), those wetlands near first-order streams, where the primary water sources are precipitation and runoff, are most responsible for desynchronization of flow before it reaches the watershed outlet (Carter 1979, Flores 1981). The removal of wetlands positioned higher in the watershed lessens the ability of those wetlands located lower in the watershed to store flood waters (Knight 1993). If headwater wetlands are removed, flooding will be exacerbated because local runoff to wetlands in the lower reaches of the watershed will be synchronized with the arrival of surface flows from higher in the watershed (Adamus and others 1991).

Predictor FAEFF2: Wetland area is larger than 81 hectares. This predictor was derived from WET and assumes that a large wetland will have a larger water storage capacity and, therefore, more effectively alter flood flow than a small wetland with less storage capacity. WET designates a ''large wetland'' as a wetland with a surface area greater than 200 acres or 81 ha.

Predictor FAEFF3: Wetland is not connected to the surface water network. This final flood flow alteration effectiveness predictor is also derived from WET. A wetland without a connection to the surface water network will not have a permanent outlet. A wetland without a permanent outlet will store most precipitation or runoff that enters it, preventing the water from entering the stream network and increasing flood flows. Any reduction in flow from a wetland to the surface water network will facilitate desynchronization.

Surface Water Quality Improvement

Surface water quality improvement occurs when suspended sediments and the nutrients or toxicants adsorbed to them are retained and deposited in a wetland. Improvement also occurs when dissolved phosphorus and/or nitrogen are removed or transformed by the wetland (Adamus and others 1991). Four opportunity and two effectiveness predictors were chosen as indicators of a wetland's water quality improvement capability (Table 1).

Predictor SWQOPP1: Wetland's watershed contains potential sources of pollutants. The presence of potential sources of pollutants in a wetland's watershed indicates the opportunity for a wetland to remove these pollutants from water that flows or runs off into the WOC. There are several different land use/land cover types typical to Northeastern landscapes that are sources of nutrients and/or toxicants. Agricultural areas can be a major source of both nutrients (fertilizers and manure) and toxicants (pesticides). Similarly, residential areas, urban areas, heavily traveled roads, dumps, and landfills can also serve as sources of nutrients and toxicants.

Predictor SWQOPP2: All of the following are true:

a. majority of the watershed is not forested or scrub shrub
b. wetland is less than 5% of watershed acreage
c. upslope wetlands comprise less than 5% of the watershed

It is very likely that there will be suspended sediments in the overland flow if all of the above criteria are met. According to WET, each individual criterion by itself is not sufficient to provide a significant opportunity to improve water quality (Adamus and others 1987). The rationale for criterion a is that a watershed not substantially covered with dense vegetation will more likely contribute overland flow laden with suspended sediments to the wetland and, therefore, provide an increased opportunity for the wetland to retain these sediments. Criterion b is based on the known positive correlation between both nutrient and suspended sediment availability and watershed area (Costa 1977, Dunne and Leopold 1978). The justification for criterion c is similar to that of predictor FAOPP1; the opportunity to perform water quality improvement will be reduced if upslope wetlands have already performed the function.

Predictor SWQOPP3. Average slope of the wetland's watershed is greater than 10%. Steep slopes are often associated with increased soil erosion rates, and thus, more suspended sediment is contained in the watershed's runoff. WET designates a wetland watershed with an average slope of greater than 10% as most likely to receive high concentrations of suspended sediments. This percentage is similar to recommendations by the NHCE assessment method's 8% (Ammann and Stone 1991) and the Planning Manual for Vermont Municipalities (1993) 8–15% steep slope range.

Predictor SWQOPP4: Wetland type is riparian. Riparian wetlands, located adjacent to rivers and streams, are occasionally flooded by adjacent surface waters, but can also be dry for long portions of the growing season (Mitsch and Gosselink 1993). Because riparian wetlands occur between the uplands and the stream network, they can be inundated with both stream water and surface water runoff (Brinson 1988). Riparian wetlands are often identified as the most important wetlands for surface water quality protection (Gilliam 1994) because their location allows them to intercept and treat runoff that would otherwise directly enter the stream network. Recent research in Vermont showed that riparian wetlands connected directly to the surface water network were associated with reduced phosphorus export from several watersheds (Weller and others 1996).

Predictor SWQEFF1: The soil type underlying a wetland is either histosol or frequently flooded mineral soil with both high clay and high organic matter content. This predictor of water quality improvement effectiveness was derived from NC-CREWS, VTWEF, and HGM. The type of soil underlying a wetland will directly influence the transformation and removal of nutrients (Adamus and others 1991). Histosols, a soil type with high organic matter content, have high cation exchange capacities (Mitsch and Gosselink 1993). Fine-grained mineral soils (clays) also retain phosphorus because of the presence of aluminum and iron (Richardson 1985). In addition, flooded soils create the anaerobic conditions required for denitrification. Therefore, a wetland soil with both high clay and high organic matter content which is also frequently flooded would have powerful water treatment capabilities. Although rare, a soil with all of these characteristics would be highly effective at water quality improvement.

Predictor SWQEFF2: Wetland is located near an intermittent or first-order stream. Similar to FAEFF1, this predictor is meant to account for landscape position by selecting those wetlands located in a watershed's upper reaches. Although a Minnesota study showed positive correlations between water quality and wetland density close to the mouths of streams (Johnston and others 1990), the majority of evidence is not consistent with this finding. Studying a Maryland watershed, Whigham and others (1988) concluded that as water moves into streams closer to the mouth, the percentage of flow contacting the wetlands decreased, resulting in the removal of less phosphorus. Other studies have reached similar conclusions, finding headwater wetlands to be more significant in removing pollutants (Brinson 1988, Weller and others 1996).

Wildlife Habitat

Wildlife habitat has been defined as the environmental factors, including food, water, cover, and their spatial distribution, that a species needs to survive and reproduce (DeGraaf and others 1992). Wetlands provide habitat for a variety of species of invertebrates, amphibians, reptiles, birds, fish, and mammals. Our goal was to develop a set of general effectiveness predictors for the provision of wildlife habitat (Table 1). We recognize that general predictors do not accurately reflect the requirements of all obligate or facultative wetland wildlife species. In a screening tool, however, the intended result is a group of wetlands representing a wide range of effective wildlife habitats. The following predictors were derived from the Rhode Island GIS-based wetland wildlife habitat assessment method (Golet and others 1994) except where noted.

Predictor WL1: Wetland size is larger than 100 hectares. Size is often cited as an important factor in the effectiveness of a wetland in providing wildlife habitat (Golet 1976, Brown and Dinsmore 1986, Harris 1989, Kent 1994). Size requirements for different species vary significantly, with larger mammals usually having the most extensive areal habitat requirements. However, size is also relevant to a wetland's invertebrate population. Invertebrate diversity can increase with wetland size as a result of increasing numbers of niches (Hicks 1996). One hundred hectares was chosen as an appropriate size based on Golet's (1976) methodology. This particular size is also supported by Kent's (1994) conclusion that interior species require at least 100 ha of habitat.

Predictor WL2: There is at least one wetland of a different type bordering the wetland being considered. This predictor is intended to be a measure of habitat diversity. A wetland with one assemblage of plant species bordering a wetland with a different assemblage of plant species represents an increase in habitat diversity. The assortment of plant species, representing a diversity of growth forms and seed maturity dates, will provide a wider range of wildlife niches (Knight 1993).

Predictor WL3: Wetland type is the least common in relation to all other wetlands in the watershed. Those wetlands least common in relation to all other wetland types in a given watershed are likely to provide habitat niches for uncommon or rare animal species. Golet and others (1994) argue that rare wetland types significantly enhance the overall ecological diversity of the landscape.

Predictor WL4: Wetland is connected to the surface water network. This predictor is derived from WET. A wetland is likely to support a greater diversity and/or abundance of fish and invertebrates if the wetland is connected to the surface water network. This indicator is given a high ''confidence in ranking'' by WET and is similar to predictors in NC-CREWS (1996) and the Rhode Island GIS wildlife methodology (Golet and others 1994). All three sources refer to the general notion that lakes and rivers add to the habitat diversity of adjacent wetlands. Connection to the surface water network provides access for fish to wetland spawning and feeding grounds. Hicks (1996) specifically notes that surface water networks aid in the dispersal and colonization of invertebrates in wetlands. It should also be noted, however, that amphibian populations in wetlands connected to the surface water network are likely to suffer increased predation rates and are therefore likely to be smaller and less diverse than amphibian populations in more isolated wetlands.

Predictor WL5: Wetland is completely surrounded by a minimum of 100 m of natural vegetation. The most common cause of wildlife population reduction is the alteration of surrounding natural vegetation through agriculture, silviculture, and construction (Brown and others 1990). Anthropogenic disturbance from surrounding urban, residential, and agricultural land uses impacts wetland wildlife through pollution, noise, harassing, hunting, and poaching (Brown and others 1990). Major roads can prove to be impassable barriers to many small wildlife species (Mader 1984) and a high source of mortality for large species (Harris 1988). Anthropogenic land use and its associated increase in edge can increase the number of exotic invasive species and opportunistic species that either compete with or prey on interior species (Harris 1989, Kent 1994). Harris (1989) suggests a buffer of at least 100 m to compensate for negative edge effects.

Predictor WL6: Wetland is hydrologically connected to another wetland within 400 m. Predictor WL7: Presence of natural vegetation corridor to another wetland within 400 m. The final two wildlife habitat predictors are meant to address the importance of both spatial distribution and connectivity to wetland wildlife habitat suitability. For many large wetland-dependent species, a single wetland cannot supply every biological need required during the life cycle (Leibowitz and others 1992). Harris (1984, 1989) and Harris and Atkins (1991) have written extensively about animals' requirements for movement corridors between areas of suitable habitat in this age of fragmented landscapes. Brown and others (1990) noted that many species prefer riparian corridors for movement between wetlands. Golet (1976) identifies 400 m as optimal spacing between Northeastern wetlands for wildlife habitat suitability.

Automation

The methodology was automated using ARC/INFO GIS software (Environmental Systems Research Institute, Redlands, CA). This Automated Assessment Method for Northeastern Wetlands (AMNEW) consists of a suite of eight ARC Macro Language (AML) programs that run in the ARC/INFO GRID module. The first program processes U.S. Geological Survey (USGS) DEM data for use in subsequent wetland watershed generation. The next program delineates individual wetland watersheds and assigns surrounding land use/land cover attributes to each wetland. The resulting attributed wetland grid is used as input to the remaining functional assessment programs, which separately analyze predictors for flood flow alteration, surface water quality, and wildlife habitat. The final data output from the AMNEW program suite are three wetland grids containing only those wetlands likely to perform each of the three wetland functions.

The eight specific AMLs are available through the Internet. The address is as follows: http://nature.snr.uvm.edu/mwatzin/amnew.html.

Study Area and Data Sources

The AMNEW method was applied and tested in the Vermont portion of the Lake Champlain Basin, a 21,326-km^2 drainage area that also includes portions of New York and the Canadian Province of Quebec (Figure 1). Soils and topography vary across the extent of the basin. The climate is cool and temperate with an average annual precipitation that varies from 127 cm in mountainous areas to 76 cm in the valley (Lake Champlain Basin Program 1996). The Stevens Brook, LaPlatte River, Lewis Creek, and Little Otter Creek watersheds were selected as test sites based on digital spatial data availability.

The accuracy of all AMNEW results depend on the accuracy of the input data. The following description of the data used as input addresses issues of both data source and scale. All spatial data sets used as input are enumerated in Table 2. The two primary data sets used warrant a more thorough description. A classified Landsat TM image acquired in May 1988 was used for land cover data. Classification of 16 modified Anderson level II/III classes (Anderson and other 1976) was performed by the Environmental Protection Agency (EPA Region 1, Boston, MA) using both unsupervised and supervised classification. An extensive field survey was performed and determined an overall mapping accuracy of 80% (unpublished data, EPA Region 1, Boston, MA). The land cover classes included the following six wetland categories: deciduous forested, coniferous forested, mixed forested, scrub shrub/emergent, scrub shrub, and emergent/open water. These data have a 30-m cell size. USGS 7.5 minute, 30-m spaced DEMs were used for the automatic delineation of individual wetland watersheds. A test using coarser scale 90-m DEMs did not produce satisfactory results.

An evaluation of AMNEW's ability to select functionally significant wetlands was conducted by comparing those wetlands selected by the GIS tool to wetlands known to be functionally significant through field investigations. Several wetlands in the study watersheds were visited by Vermont (VT) ANR staff in 1988, the same year that the Landsat image used as a data source by AMNEW was acquired. Functional assessments were performed during these visits using VTWEF. This method is based on the Vermont Wetland Rules (Water

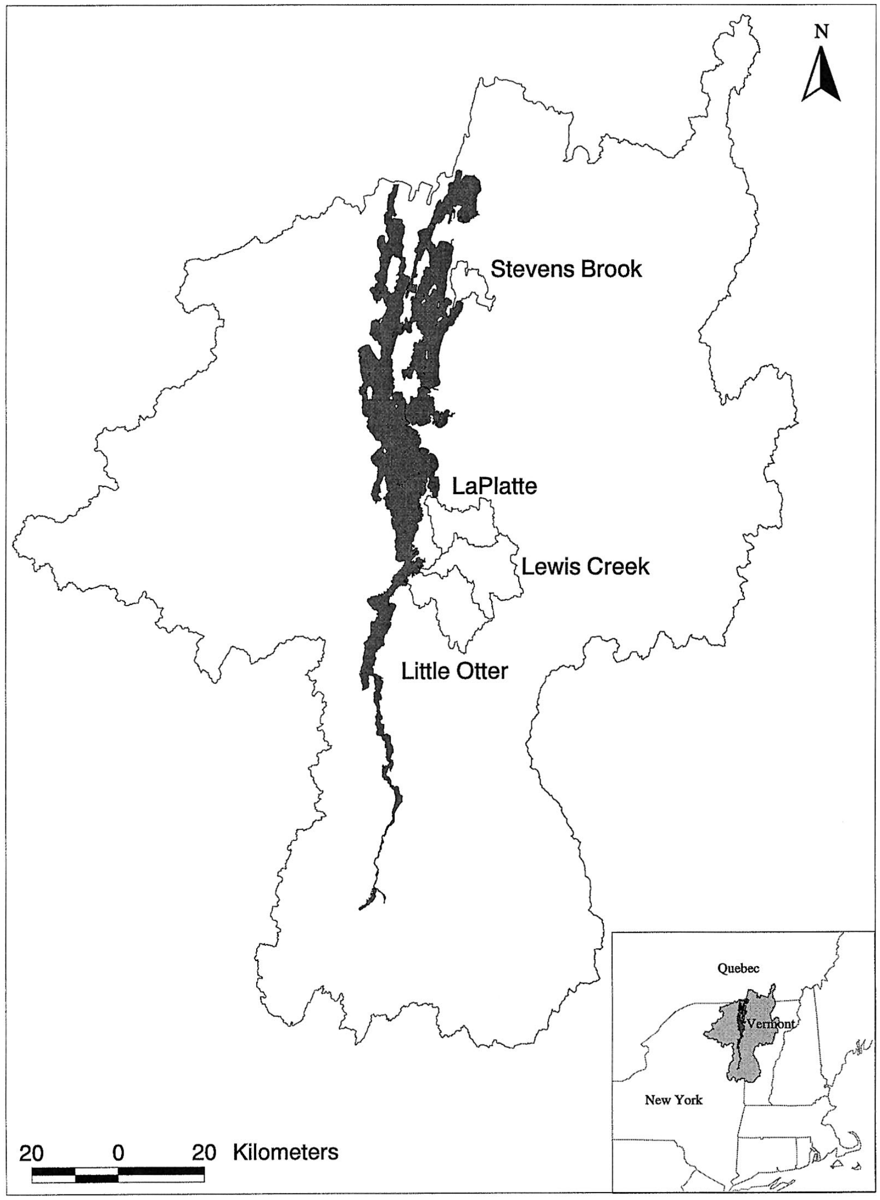

Figure 1. Locations of the four study watersheds in the Lake Champlain basin. The shaded area is Lake Champlain. The insert box shows the location of the Lake Champlain basin relative to the Northeastern United States and Canada.

Resources Board 1990) and consists of a preliminary field checklist of criteria for 10 specific wetland functions, including flood water storage, surface water protection, and wildlife and migratory bird habitat.

Binhammer (1994) assessed wetlands in each of the study watersheds as part of a study to determine significant wetlands worthy of acquisition and permanent protection. Binhammer developed a field ranking system to quantify a wetland's cultural, physical, and biological attributes. Included in this assessment were measurements for flood storage potential, surface water protection potential, and general wildlife value. Each wetland was ranked as either unknown, none, low, medium, or high for each function or value.

Results and Discussion

The number of wetlands selected by the predictors for each function varied significantly (Table 3). Only two of the four study watersheds had dams. In these watersheds, Little Otter and Lewis Creek, AMNEW selected only a small percentage of wetlands as hydrologically influenced by these dams. For this predictor, as well as others that incorporate hydrologic connections, AMNEW considers wetlands individually rather than as part of a wetland complex, therefore, only the wetland that actually intersects the stream is selected. Even if that one wetland is contiguous with others, we did not judge it appropriate to assume that every wetland in a

Table 2. Spatial data sets used as input to AMNEW

Data layer	Scale / resolution	Source
Landsat TM land cover	30 m	EPA
Digital elevation model	7.5 min, 30 m	USGS
Watershed boundaries	1:24,000	UVM
Surface water	1:20,000	VCGI
Soils	1:20,000	NRCS
Roads	1:5000	VCGI
Landfills	1:24,000	VCGI
Dams	1:24,000	USFWS

EPA = Environmental Protection Agency Region 1, Boston, MA; NRCS = Natural Resources Conservation Service, Williston, VT; USFW = U.S. Fish and Wildlife Service, Essex Junction, VT; USGS = U.S. Geological Survey, Reston, VA; UVM = University of Vermont Spatial Analysis Lab, Burlington, VT; VCGI = Vermont Center for Geographic Information, Burlington, VT.

complex, which can represent many different wetland types, is hydrologically connected and shares similar hydrologic characteristics. If we did select every contiguous wetland, the selection numbers could be much larger. For example, in the Little Otter watershed, one wetland adjacent to the main river channel immediately downstream of a dam was connected to a complex of 57 other wetlands. This complex was approximately 1.5 km long, making it unlikely that every wetland was under the same hydrologic influence as the wetland immediately downstream of the dam.

The small number of wetlands selected for the flood flow alteration predictor FAEFF2 was similarly affected by our focus on individual wetlands, not complexes. Because wetlands were considered individually, the size threshold was rarely reached.

Only 1 of the 2382 wetlands in the four watersheds was found to be surrounded by greater than 50% impervious surfaces (predictor FAOPP3). This is consistent with the land-use characteristics of each of the four study watersheds. The dominant land-use type in each of the four watersheds is either agriculture or forested land; there is relatively little of the urban and residential land use types considered as impervious by AMNEW. A larger number of wetlands would probably be selected in a more developed watershed.

Several trends are evident in the selection results for the water quality improvement function. Few wetlands were selected for SWQOPP2, but this is a reasonable result considering that each wetland was required to meet three selection criteria instead of the single criterion typical of other AMNEW predictors. Predictor SWQEFF1, which considers wetland soils, proved to be the most restrictive predictor. Very few wetlands were selected by this predictor in all of the watersheds. In the large Lewis Creek watershed, only two wetlands met the criteria. Any wetlands selected by this predictor were underlain by histosols. No wetlands met the frequently flooded mineral soil criterion. Further examination of the soils data revealed several soil types that were characterized by either frequent flooding and high organic matter content or frequent flooding and high clay content. No soils in any of the watersheds were frequently flooded with both high organic matter and high clay content.

In Stevens Brook, the smallest watershed with the flattest topography, only six wetlands (or 2% of the total) had individual watersheds with an average slope greater than 10% (SWQOPP3). In contrast, in the Lewis Creek watershed, which has the highest amount of topographic variation of any study watershed, SWQOPP3 selected 495 wetlands, or 58% of the total. Obviously, this indicator is most effective where there is significant topographic variation.

Table 3. AMNEW selection statistics for each predictor. Data entries represent the number of wetlands selected by AMNEW for each predictor of the three functions (flood flow alteration, water quality improvement, and wildlife habitat) in each of the four study watersheds

	Study watershed			
	Stevens	LaPlatte	Little Otter	Lewis
Total # of wetlands	265	508	767	842
Dam influence	0	0	15	35
Predictor:				
FAOPP1	108	260	323	378
FAOPP2	135	261	348	496
FAOPP3	1	0	0	0
FAOPP4	7	86	252	21
FAOPP total*	194	419	621	687
FAEFF1	103	229	257	322
FAEFF2	0	1	0	0
FAEFF3	122	245	294	303
FAEFF total*	148	309	405	466
SWQOPP1	202	312	432	506
SWQOPP2	16	20	40	18
SWQOPP3	6	188	169	495
SWQOPP4	94	210	403	470
SWQOPP total*	220	425	597	764
SWQEFF1	18	13	23	2
SWQEFF2	113	215	223	339
SWQEFF total*	129	216	244	340
WL1	0	34	135	83
WL2	159	240	457	495
WL3	8	4	7	11
WL4	94	210	403	470
WL5	8	30	56	106
WL6	148	367	513	699
WL7	33	96	202	231
WL total*	219	442	695	801

*Predictor Totals Exclude Overlaps.

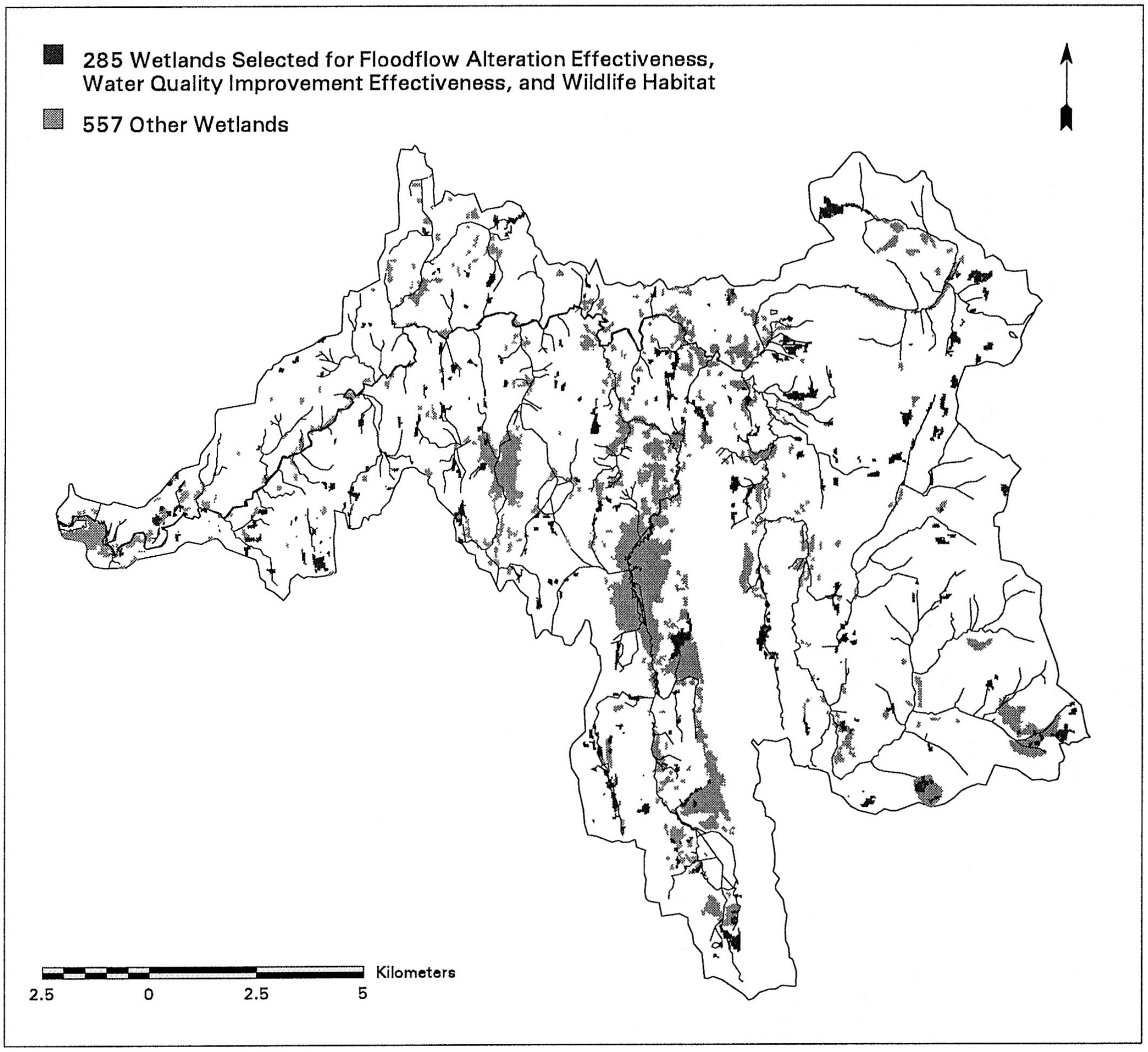

Figure 2. Wetlands selected in the Lewis Creek watershed. The darkest areas represent those wetlands performing all three of the wetland functions assessed by AMNEW.

Of the three wetland functions considered by AMNEW, the wildlife habitat AML selected the largest number of wetlands overall and, therefore, seems to have the "broadest brush." The flood flow alteration and surface water quality portions of AMNEW first selects those wetlands that have the opportunity to perform each function, then further reduces the selected set by reselecting only those wetlands that meet additional effectiveness criteria. In contrast, the wildlife habitat portion of the tool performs only a single round of selections according to a relatively large number of predictors (seven) and makes no further reselections.

Wildlife habitat predictor WL1, which considers wetland size, selected no wetlands in the Stevens Brook watershed but many in the Little Otter watershed, where many individual wetlands are contiguous, sometimes forming very large wetland complexes. For this predictor, unlike the predictors for the flood flow function based on size, the overall size of the wetland complex was considered because most wildlife will use multiple adjacent wetlands to satisfy different requirements even if there is no hydrologic connection.

Although many wetlands in each of the study watersheds were connected by natural vegetation corridors, relatively few wetlands (1–7% in the four watersheds) were surrounded by 100 m of natural vegetation (WL5). Wetlands were most commonly bordered by agricultural land, suggesting that Vermont's agricultural landscape may negatively affect the wildlife habitat suitability of the state's wetlands. More wetlands, on average, were selected because of the presence of a connecting corridor of natural vegetation (WL5) than were selected because of a hydrologic connection (WL6).

Figure 2 shows wetlands in the Lewis Creek water-

Table 4. A comparison of AMNEW predictions and available Vermont Agency of Natural Resources (ANR) field assessments in the test watersheds. AMNEW's percentage was obtained by summing the area of the individual wetlands performing the given function and dividing that sum by the area of the total wetland complex. For ANR results, "yes" means the function is begin performed and "no" means the function is not being performed

Wetland complex test method	Wetland function		
	Flood flow alteration	Water quality	Wildlife habitat
Stevens' Brook Marsh			
AMNEW	70%	94%	89%
ANR	yes	yes	yes
Shelburne Pond			
AMNEW	97%	97%	100%
ANR	no	no	yes
LaPlatte River Marshes			
AMNEW	43%	91%	99%
ANR	yes	yes	yes
Little Otter			
AMNEW	14%	91%	100%
ANR	yes	yes	yes

Table 5. A comparison of AMNEW predictors and wetland evaluations by Binhammer (1994). AMNEW's percentage was obtained by summing the area of the individual wetlands performing the given function and dividing that sum by area of total wetland complex. Binhammer's results are measurements of the likelihood of the three functions (unknown, none, low, medium, or high)

Wetland complex test method	Wetland function		
	Flood flow alteration	Water quality	Wildlife habitat
Stevens' Brook Marsh			
AMNEW	70%	94%	89%
Binhammer	none	high	high
LaPlatte Floodplain Forest			
AMNEW	100%	100%	100%
Binhammer	unknown	medium	high
Shelburne Pond			
AMNEW	97%	97%	100%
Binhammer	none	high	high
LaPlatte River Marshes			
AMNEW	43%	91%	99%
Binhammer	none	high	high
Bristol Pond			
AMNEW	88%	94%	100%
Binhammer	low	medium	high
Lewis Creek			
AMNEW	14%	97%	98%
Binhammer	none	high	high
New Haven Cedars			
AMNEW	77%	95%	99%
Binhammer	medium	medium	high
Little Otter			
AMNEW	14%	91%	100%
Binhammer	none	medium	high

shed, where an overlap of the three functions occurs. Of all the wetlands in the Lewis Creek watershed, these wetlands should be considered the most functionally significant. There is no particular pattern to the distribution of these wetlands except that few are located along the main river stem.

Comparisons between those wetlands selected by AMNEW and those selected by the VT ANR and Binhammer (1994) as functionally significant and worthy of protection showed reasonable and encouraging correspondence (Tables 4 and 5). However, differences in how VT ANR, Binhammer, and AMNEW evaluated the wetland complexes must be considered when interpreting the results. VT ANR and Binhammer considered the entire wetland complex in evaluating each of the three functions. Because we believe an examination of the unique characteristics of each individual wetland and its specific watershed is generally the most accurate way to assess wetland function, for most predictors, AMNEW examines wetlands individually. Differences in treatment of wetland complexes are the cause of some apparent differences in functional assessments. For example, VT ANR found the Stevens Brook Marsh complex to be performing the water quality improvement function (Table 4), and Binhammer found the complex as having a high potential to perform this function (Table 5). About 94% of the wetlands in this complex were found to be performing the water quality function by AMNEW. This result was obtained by summing the area of the individual wetlands performing the function and dividing that sum by the total area of the wetland complex.

VT ANR staff visited four wetland complexes in the study watersheds. In most cases, there is agreement between AMNEW's results and VT ANR's assessments. For example, in the Steven's Brook Marsh complex, AMNEW predicted many individual wetlands in these complexes were performing each of the three functions. The most significant exception occurs when considering the flood flow alteration function. AMNEW predicted that almost all wetlands in the Shelburne Pond complex were performing this function, but VT ANR suggested this complex was not performing this function, largely because the wetlands are not connected hydrologically to any downstream water body. In contrast, in the Little Otter complex AMNEW found very few wetlands performing flood flow alteration, but ANR determined that the entire complex was performing this function.

Binhammer judged eight wetland complexes in the study watersheds worthy of protection. In five of these wetland complexes (Stevens Brook Marsh, Shelburne Pond, LaPlatte River Marsh, Lewis Creek, and Little Otter), there are conflicting results between AMNEW's predictions and Binhammer's judgments for the flood flow alteration function. In each case, AMNEW predicts wetlands in the complex are performing flood flow alteration, whereas Binhammer concludes there is no potential to perform this function. Binhammer always assumed that lakeside wetlands, whose water level fluctuates with lake level, have no flood control function. All five of these wetlands were lakeside wetlands. We do no agree with Binhammer's assumption and remain confident that our set of predictors are a better evaluation of the ability to desynchronize flood flows.

Two wetland complexes were evaluated for flood flow alteration by both VT ANR and Binhammer (LaPlatte River Marshes and Little Otter). For both these complexes, there is disagreement between VT ANR's and Binhammer's conclusions (Tables 4 and 5). AMNEW predicted some wetlands in both complexes were performing the function, but others were not. This result provides some support for the individually targeted approach of AMNEW and suggests a need for greater understanding of this function.

From this preliminary evaluation of AMNEW's results, it seems that this tool was able to identify successfully those wetlands performing both the water quality improvement and wildlife habitat functions. There were, however, some discrepancies between AMNEW's predictions for the flood flow alteration function and the judgments about flood flow alteration made by both VT ANR and Binhammer. It is possible that field investigations of sites where these discrepancies exist revealed factors that our method could not consider. Only a full-scale field investigation can resolve these questions.

Conclusions

AMNEW is a comprehensive GIS screening tool that can efficiently identify those wetlands in the Northeastern region that have the potential to be functionally important. AMNEW can provide resource managers and planners throughout the Northeast with a way to locate functionally significant wetlands, saving time and resources by directing field investigations to those wetlands identified by the tool as potentially important. AMNEW should never be used as the sole source of information for making decisions related to wetland function. Rather, it should be viewed as one part of an overall approach to understanding wetland function. Because knowledge about wetland processes is still evolving, AMNEW should be expanded and refined as our scientific understanding of wetland functions continues to improve.

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