Application of Multi-Temporal Landsat 5 TM Imagery for Wetland Identification

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Abstract

Multi-temporal Landsat 5 Thematic Mapper (TM) imagery was evaluated for the identification and monitoring of potential jurisdictional wetlands located in the states of Maryland and Delaware. A wetland map prepared from single-date TM imagery was compared to a hybrid map developed using two dates of imagery. The basic approach was to identify land-cover vegetation types using spring leaf-on imagery, and identify the location and extent of the seasonally saturated soil conditions and areas exhibiting wetland hydrology using spring leaf-off imagery. The accuracy of the wetland maps produced from both single- and multiple-date TM imagery were assessed using reference data derived from aerial photographic interpretations and field observation data. Subsequent to the merging of wetland forest and shrub categories, the overall accuracy of the wetland map produced from two dates of imagery was 88 percent compared to the 69 percent result from single-date imagery. A Kappa Test Z statistic of 5.8 indicated a significant increase in accuracy was achieved using multiple-date TM images. Wetland maps developed from multi-temporal Landsat TM imagery may potentially provide a valuable tool to supplement existing National Wetland Inventory maps for identifying the location and extent of wetlands in northern temperate regions of the United States.

Introduction

Wetlands are lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface (Cowardin *et al.*, 1979; Lyon, 1993). Their beneficial functions have been well documented and include hydrologic regulation, erosion protection, and water quality control mechanisms (Braddock and Huppmann, 1995). Additionally, wetlands provide a wide range of habitat types for a multitude of flora and associated fauna species, and are among the most productive and diverse ecosystems on Earth (Jensen and Salisbury, 1972). Over the past 200 years, wetland habitats in the conterminous United Stated have been reduced by approximately 50 percent (Lyon, 1993). This high rate of wetland loss has resulted in the establishment of numerous federal, state, and local government agency regulatory programs to slow or eliminate net wetland losses.

The National Wetland Inventory (NWI) was initiated in 1975 by the U.S. Fish and Wildlife Service (FWS) to map, inventory, and monitor the status and trends of wetlands throughout the United States on a 10-year reporting cycle (Kiraly *et al.*, 1990). The approach often involves the use of leaf-off national high altitude photography (NHAP) and incorporates standard photographic interpretation and photogrammetric techniques. Although effective, this photo-based process is time consuming, relatively expensive, and cannot be rapidly updated. Currently, researchers are evaluating numerous advanced technologies to develop more cost-effective and rapid methods to assist in long-term wetland monitoring.

The purpose of this study was to evaluate the application of moderate spatial (30-meter) and spectral (seven-band) resolution satellite imagery and digital image analysis techniques to aid in the identification of potential jurisdictional wetlands. Collaboration with U.S. Environmental Protection Agency's (EPA) Region III wetland scientists provided a means for assessing the utility of wetland maps to assist environmental managers in conducting permit reviews under Section 404 of the Clean Water Act. The final wetland maps generated in this study were used to complement the existing FWS/NWI maps for the study area.

Wetlands are inherently dynamic systems. As such, monitoring efforts limited to single date of observation are typically insufficient to capture seasonal dynamics related to crucial hydrologic processes and other dynamic conditions. The potential value of multiple-date TMimage analysis for wetland mapping has been noted by other researchers (Koeln *et al.*, 1986; Jacobson *et al.*, 1987). They reported low classification accuracies of wetlands mapped using single-date TM images and suggested that a multi-temporal approach could improve wetland category accuracies. The analysis of a single-date TM image yields information at a single point in time; therefore, wetlands that exhibit seasonally saturated conditions are commonly confused with their upland counterparts. Certain wetland types are particularly vulnerable to confusion using a single date of imagery. They include forested and agricultural wetland types that exhibit characteristic seasonally saturated soils during the growing season and typically have a high degree of canopy closure and leafy vegetation cover.

Study Area

The study site was oriented to conform to the Millington, Maryland-Delaware, 7.5-minute U.S. Geological Survey (USGS) quadrangle (Figure 1). It was selected because of its diverse

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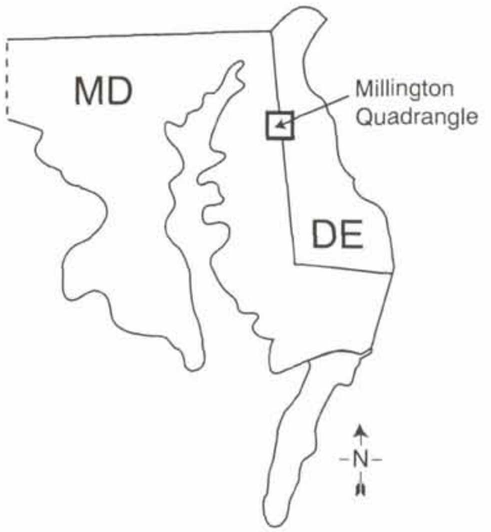

Figure 1. Location of the study site represented by the Millington 7.5-minute quadrangle.

combination of upland and wetland vegetation over a relatively small area. The site is located within the Virginian Province of the Mid-Atlantic coastal plain and consists of nearly level to undulating plains dissected by ravine-like drainage ways, with alluvial deposits in the floodplains and marshes. Soils range from well to poorly drained, and were formed from silty and silty loam materials. Some areas have no surface drainage and drain slowly through depressions that provide opportunities for ground water recharge.

The Millington site has both upland and palustrine wetland forests, shrubs, emergents, and agricultural lands. Approximately 40 percent of the site was non-managed woodland at the time of the study. Wooded uplands consisted of Oak-Hickory (*Quercus* sp./*Carya* sp.), Oak-Gum (*Quercus* sp./*Bumelia lanuginosa*), various eastern hard-Pine species (*Pinus* sp.), Oak-Pine (*Quercus* sp./*Pinus* sp.), and Elm-Ash-Maple (*Ulmus* sp./*Fraxinus* sp./*Acer* sp.) type forests. Wooded wetlands consisted of Oak-Willow (*Quercus* sp./*Salix* sp.), Oak-Pine, Oak-Gum, and Elm-Ash-Maple type forests. Most of the remaining area was in row crop production. Through the majority of the area, drainage was the predominant concern, because most agricultural locations experience seasonally high water tables and contain poorly drained soils.

Methods

The two dates of TM images used in this study corresponded to path 14/row 33 of the World Wide Reference System 2 (WRS-2). The 11 June 1988 TM image of the study area was used to develop the initial land-cover map, and the 20 April 1986 TM image was used to generate the non-hydric and hydric data coverage. The 1986 spring imagery was selected because it represented the closest available data to the 1988 leaf-on imagery that corresponded to the "normal" seasonally wet period (determined using available meteorological records).

A three-step approach produced a land-cover map for both upland and wetland land cover types. First, an initial land-cover map was developed using late spring, leaf-on imagery. Second, the distribution and extent of upland (non-hydric) and wetland (hydric) categories were established using early spring, leaf-off imagery. The non-hydric versus hydric data coverage was generated from analysis of TM band 5 (1.55 mm to 1.75 (mm) which is sensitive to differential moisture in surficial soils and plant tissues (Thenkabail *et al.*, 1994). Lastly, both coverages were analyzed using a GIS rule-based classification model in an attempt to improve the classification accuracies of the wetland classes. The hypothesis was that classification accuracies of wetlands extracted from single-date imagery could be significantly improved by revision with information derived from the second date of TM imagery that was selected to coincide with the seasonal period of wet soils.

The 11 June 1988 imagery was selected to allow maximum discrimination of wetland vegetation. Jensen *et al.* (1986) found that multispectral satellite imagery acquired in spring and early summer best distinguished palustrine persistent inland wetland types such as herbaceous, forest, and agricultural wetland categories. The 11 June image was subset to produce a data set of the study area that included TM band 2 (0.7 mm to 0.8 mm), band 3 (0.8 mm to 0.9 mm), band 4 (0.9 mm to 1.0 mm), and band 5 (1.55 mm to 1.75 mm) (Plate 1a).

TM imagery used to identify seasonally saturated soils in the northern temperate regions of the United States should be acquired during the annual inundation or wet period occurring in early spring, before vegetation emerges and obscures soils, and during a year representative of typical hydrologic conditions for a specific location. Historical precipitation and stream flow records from Maryland and Delaware were examined to determine appropriate dates that represent "normal" seasonally wet periods for the study site (NOAA, 1986–1990; USGS, 1986–1990). Dates of seasonal high-water conditions were compared to dates of available TM imagery in order to select the best available imagery for wetland identification. The TM image selected for analysis was acquired for a spring date so that ice and snow would not obscure the land surface but before leaf-on, a condition that could obscure soil moisture and also contribute foliar moisture content to the measurement.

Wetland Identification Protocols

Wetlands were mapped according to the three-parameter approach defined in the *Corps of Engineers Wetland Delineating Manual* (USACE, 1987). The manual defines wetlands as areas that exhibit hydrophytic vegetation, hydric soils, and wetland hydrology or standing water. A key indicator of wetland hydrology is saturation of land surfaces by water. Areas saturated with water were identified from analysis of spring leaf-off TM imagery and validated using soils information obtained from U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) soils maps. A description of the techniques used to identify wetland vegetation, soils, and hydrology follows.

Vegetation

A vegetation type coverage was produced from the single-date 11 June 1988 TM image using an unsupervised classification approach. Visible bands 2 and 3 were selected to assist in differentiating saturated surfaces from very dark features such as dark organic soils and asphalt. TM band 4 was selected because of its sensitivity to foliar structure characteristics, and band 5 to differentiate soil moisture content (Jensen *et al.*, 1986; Lillesand and Kiefer, 1987). An unsupervised classification approach was first applied to identify signatures corresponding to unique spectral categories, followed by a maximum-likelihood statistical classifier utilizing the statistics generated from the cluster analysis to assign each pixel in the TM image to a specific spectral category (Weerackoon and Mace, 1990). Post-classification sorting into land-cover categories was accomplished using stereoscopic interpretation of USGS National Aerial Photography Program (NAPP) 1:40,000-scale color infrared (CIR) aerial photographs, USGS 7.5-minute topographic maps, and USDA-NRCS soils maps.

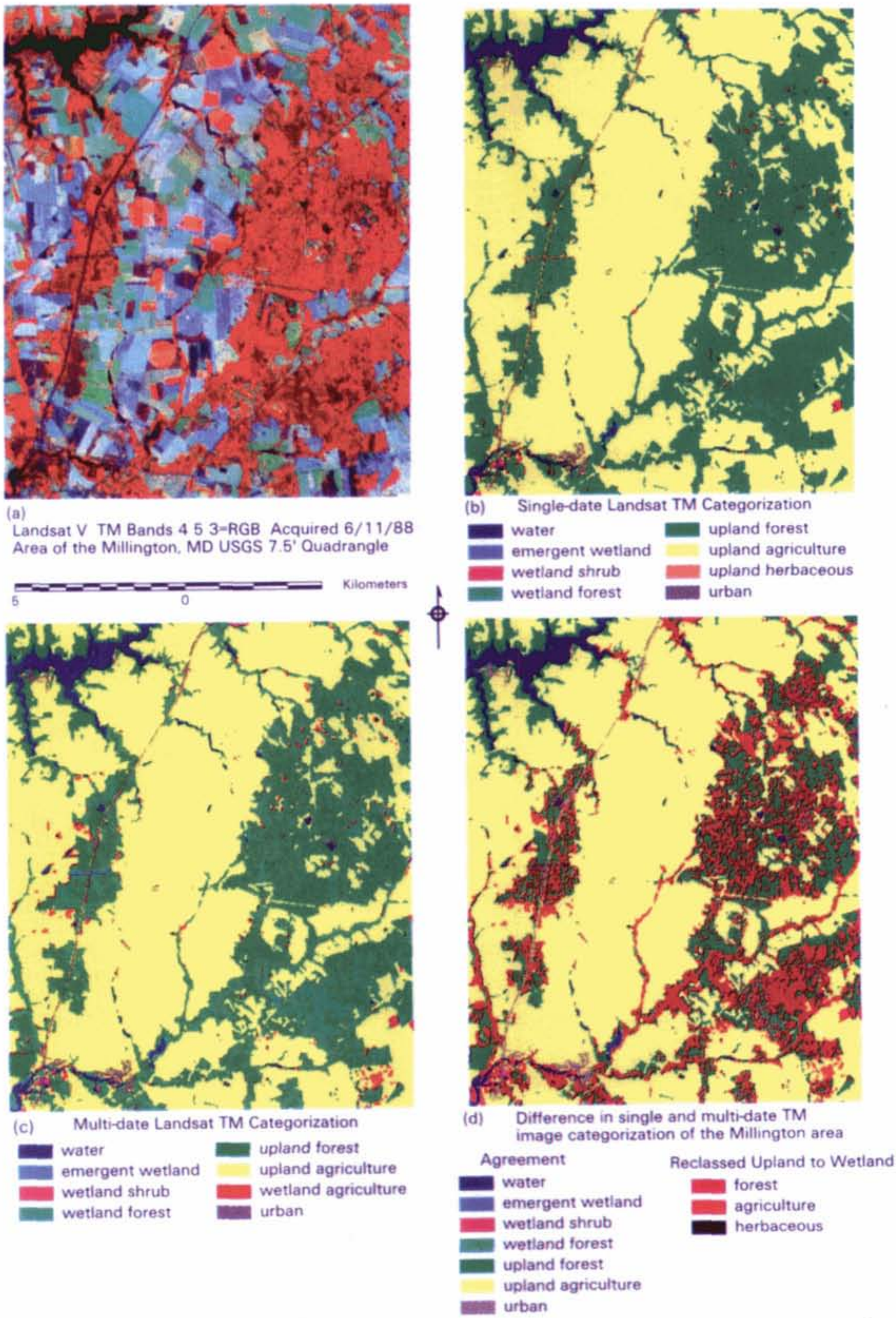

Plate 1. Results of the Landsat 5 TM land-cover imagery analysis for the Millington 7.5-minute quadrangle.

The urban areas and a fish hatchery located in the study area did not exhibit unique spectral response and were confused with agriculture and forest categories. To minimize confusion, urban areas and the fish hatchery were manually edited in the classification process on the basis of visual interpretation of the TM imagery. Roads typically had a spectral response similar to observed barren soils. (Barren soils were aggregated with the upland agriculture category.) Linear features that were categorized as barren soil, but could be visually interpreted as roads using aerial photographs and USGS 7.5-minute maps, were manually edited to the urban category. The result of this initial classification from single-date TM imagery is presented in Plate 1b. The classification system used to label land-cover classes is consistent with the NWI system (Table 1).

Soils

Hydric soils are defined as soils that are saturated, flooded, or ponded long enough during the growing season to develop wetland characteristics (USACE, 1987). Soils maps, provided by the USDA-NRCS, were used as ancillary data to identify areas that exhibit hydric soils. These data were only available in hardcopy 1:24,000-scale map format and were used to calibrate the gray-level threshold levels discussed below.

Hydrology

Wetlands occur in areas where the water table is usually at or near the surface or where land is covered by shallow water (USACE, 1987). Water absorbs the energy of infrared wavelengths, resulting in lower reflectance values for saturated areas than for drier upland sites. The image was divided into upland (non-hydric) and wetland (hydric) categories by applying gray-level thresholding techniques as described by Work and Gilmer (1976) and Lillesand and Kiefer (1987) to the infrared bands of spring leaf-off TM imagery. Various density slices of TM band 5 were visually interpreted until a brightness threshold separating wetlands from uplands was found. Visual analysis of the infrared TM bands 5 and 7 revealed that band 5 best discriminated between dry and wet areas. USDA-NRCS soils maps and USGS 7.5-minute topographic maps were both utilized as ancillary data sources.

GIS Rule-Based Classification Model

Sader *et al.* (1995) found that rule-based methods for forest wetland classification performed significantly better than unsupervised classification at multiple sites in the northeast United States. We implemented a simple rule-based model on a pixel-wise basis using ARC/GRID as the platform supporting the analysis of raster data coverages corresponding to the vegetation type and hydrologic soils condition. The model outcome was a new data coverage where each pixel was re-coded based on both vegetation type and characteristic hydric or non-hydric soils groupings. Hydric soil conditions coincided with wetland cover types and non-hydric soil conditions with upland land-cover categories. For example, pixels categorized as forest in the classification of early summer TM imagery were recoded to wetland forest if they coincided with a hydric soils pixel. Those pixels coinciding with non-hydric soils pixels kept their original upland classification value (Table 2).

TABLE 1. LAND-COVER CLASSIFICATION SYSTEM

1.0 Open Water
2.0 Wetland (Palustrine)
2.1 Forest
2.2 Shrub
2.3 Emergent
2.4 Agriculture
3.0 Upland
3.1 Forest
3.2 Shrub
3.3 Herbaceous
3.4 Agriculture
4.0 Urban

Cartographic Generalization and Conversion to Vector Format

The vegetation classifications produced from single-date and multiple-date TM imagery were generalized to eliminate features smaller than the 0.8 hectare minimum mapping unit (MMU). These features could not be repetitively mapped and serve only to clutter the classification (salt and pepper). Areas that were smaller than the MMU were eliminated in the generalization process. Polygons less than 0.8 hectare in area were typically made up of edge pixels, or mixed pixel types (more than one cover type). Individual pixels or small groups less than nine pixels (0.8 hectare) were generalized using a smoothing routine that examined category values of a specified number of pixels surrounding a central pixel. The central pixel's category value in a 3- by 3-pixel window was changed to match the majority of values (majority rule) in the window. The classification of the study site was converted to vector format and stored as an ARC/INFO coverage. The single-date land-cover classification and the multi-date TM data classification that focuses on wetlands are presented in Plates 1b and 1c, respectively.

Collection and Development of Reference Data

A total of 280 reference sites were sampled to provide a reference data set for the validation of the Millington quadrangle results. The total number of sites was calculated based on the number of categories in the land-cover map. Congalton (1991) suggests obtaining data on a minimum of 30 to 50 sites per category. To ensure coverage of rare classes and thus avoid bias, approximately 21 sites were established for each of the four categories (water, wetland shrub, urban, and wetland agriculture) that in total represented approximately seven percent area coverage. The remaining 198 sites were distributed among the remaining three dominant categories (wetland forest, upland forest, and upland agriculture), proportionate to the areal extent of each class type. Table 3 summarizes the percent area, number of field investigations, and number of sites interpreted from aerial photographs used to assess accuracy for each class.

Validation data collection locations were selected using a stratified random sample design. The multiple-date land-cover classification results provided the stratification template to support the stratification for the generation of the random sampling points. Coordinates of random sites located within the Millington quadrangle were determined using a random number generator software. Points were overlaid on the categorized image and polygons that corresponded with the random site coordinates were selected for accuracy assessment. The center points of polygons were calculated and selected as the designated assessment locations. It should be noted that this technique did not facilitate an evaluation of boundary accuracies.

EPA Region III personnel collected field validation data from reference sites concentrated in both wetland and forested areas. Budget restraints allowed on- site data collection at only 28 sites. Ground truth of the remaining sites was obtained through stereoscopic interpretation of 1:40,000-scale USGS-NAPP CIR aerial photographs. Locations of all reference sites were stored in an ARC/INFO coverage and plotted at a scale of 1:24,000. EPA Region III personnel overlaid the sample plots with the USGS 7.5-minute map to provide orientation of reference site locations in the field. Aerial photographs were also used in the field to locate plot centers. Sampling sites coordinates were plotted on 1:24,000-scale maps and located in the field using aerial photographs as final orientation guide. Data

Table 2. Data Layers, Variables, and Modeling Outcomes

Data Layer and Variables	Modeling Outcomes			
Unsupervised Classification	Forest (Fo)	Shrub (S)	Herbaceous (H)	Agricultural (Ag)
Hydric Soils	FoW	SW	EW	AgW
Non-Hydric Soils	UFo	US	UH	UAg

W = Wetland Class U = Upland Class E = Emergent

were collected from a circular plot 90 meters in diameter (approximately 0.8 hectares) and included information on vegetation types, soil moisture characteristics, and hydrology.

Accuracies of the single- and multiple-date TM image classifications were calculated by comparing photographic based stereoscopic interpreted and field observation reference data to the categorized data sets. Both the photographic interpretation and field observation data were entered as point attributes in ARC/INFO to produce a reference coverage that was subsequently merged with the vector format TM classification products. An ARC/INFO report was generated that listed the category codes from the reference data and classification products. This report was used to generate error matrices or contingency tables, and to calculate statements of accuracy (Congalton, 1991). Percent errors of commission (user accuracy) and percent errors of omission (producer accuracy) are also listed for each category (Story and Congalton, 1986).

Results

Single Date Classification Accuracies

The error matrices listed in Tables 4 through 7 show the correspondence between the reference data and imagery classification results. A Kappa statistic was calculated for each categorized error matrix and was presented to provide a measure of classification accuracy as a whole. The Kappa coefficient calculation indirectly incorporates all cells in the error matrix and accounts for errors of commission and omission. It measures the actual agreement minus chance agreement and indicates how well the classification performs in relation to the reference (validation) data (Congalton *et al.*, 1983; Congalton, 1991). It should be noted that the wetland emergent category was not assessed for accuracy because it had an inadequate number of pixels ($n = 332$ pixels or 0.18 percent of total pixels) to support a statistically valid accuracy assessment.

The results of the single-date TM classification are presented graphically in Plate 1b and summarized statistically in Table 4. It is evident from the statistical presentation that significant confusion existed between wetland and upland forests, and wetland and upland agriculture classes. Wetland forest was identified with an accuracy of 75 percent (omission and commission error rates of 89 and 25 percent, respectively)

Table 3. Class Type by Percent Aerial Extent, Total Number of Validation Points, and Validation Method

Land-Cover/ Land-Use Type	% Area	Total No. Sites	Method of Validation: Field Observation	Method of Validation: Photo Interpretation
Water	3	20	1	19
Wetland Shrub	1	22	1	21
Wetland Forest	17	49	12	37
Upland Forest	15	49	7	42
Upland Agriculture	61	98	5	93
Urban	1	22	1	21
Wetland Agriculture	2	20	1	19
Column Totals	**100**	**280**	**28**	**252**

and upland forests were identified with an accuracy of only 46 percent (omission and commission error rates of 4 and 54 percent, respectively). Wetland shrubs were identified with an accuracy of 64 percent (omission and commission error rates of 57 and 36 percent, respectively). Most striking was the total lack of wetland agriculture class areas. This result is less surprising owing to the emphasis placed on good drainage to facilitate the cropping of fields. The overall accuracy of the single-date seven-class classification was 68 percent, with a Kappa statistic (KHAT) of 0.59 ($n = 280$).

The overall classification accuracy results of multiple date seven class classification was 83 percent, with a KHAT of 0.79 ($n = 280$) (Table 5) and are presented graphically in Plate 1c. Similar to the single-date classification, the highest accuracies were realized for the upland agricultural (92 percent), urban (85 percent), and water (85 percent) categories. Significant improvements in the discrimination of wetland versus upland forest and in the identification of wetland agriculture were realized. Accuracies associated with upland forests increased dramatically to 84 percent (omission and commission error rates of 11 and 16 percent, respectively) compared to only 46 percent with the single-date classification. Most dramatic was the increased accuracy of wetland agriculture from zero percent using the single-date imagery to 75 percent accurate (errors of omission and commission 12 and 25 percent, respectively). Some confusion occurred between the upland forest and wetland agriculture categories, as evident by errors of commission (16 and 25 percent, respectively) and errors of omission (11 and 12 percent, respectively). Significant confusion existed between wetland shrub and wetland forest, as evident by the low accuracy for wetland shrub at 45 percent (omission 57 percent and commission 55 percent, respectively). The highest occurrence of omission and commission errors resulted from confusion between wetland forest and the upland forest and wetland shrub categories because the spectral characteristics were very similar.

Wetland forest and shrub classes were collapsed into a single woody wetland vegetation class in an attempt to improve wetland classification accuracies. The results of the six-class TM classifications are presented in Tables 6 and 7. The overall classification accuracy of the single-date six-class classification was 69 percent, with a KHAT of 0.59 ($n = 280$). This result is very consistent with that obtained from the single-date seven-class classification and did not represent a significant overall improvement. However, the poor classification accuracy of 64 percent for the wetland shrub class was upgraded to a 77 percent accurate woody wetland class. In contrast, the six-class multiple-date classification improved on the seven-class overall accuracy of 83 to 88 percent. Similarly, the poor performing wetland shrub class was combined with the wetland forest to create an 88 percent accurate woody wetland class.

Comparison of Single- and Multi-Date Classifications

Congalton *et al.* (1983) described how a pair-wise test of significance can be performed between two independent KHATs. This test calculates the difference between two error matrices and provides a determination of significance. This statistical analysis allows the comparison of the error matrices generated from

Table 4. Error Matrix and Summary Statistics for the Single-Date Landsat TM Classification

	Observed Land Cover									
	W	WS	WF	UF	UA	UR	WA	Row Total	% Correct	% Commision
Water	**17**	1	2	0	0	0	0	20	85	15
Wetland Shrub	1	**9**	0	1	2	0	1	14	64	36
Wetland Forest	0	2	**6**	0	0	0	0	8	75	25
Upland Forest	1	6	44	**45**	2	0	0	98	46	54
Upland Agriculture	0	3	2	1	**95**	3	16	120	79	21
Urban	1	0	0	0	0	**19**	0	20	95	5
Wetland Agriculture	0	0	0	0	0	0	**0**	0	0	0
Column Total	20	21	54	47	99	22	17	$n = 280$	Overall Accuracy 191/280 = 68%	$\hat{K} = 0.59$
% Omission	15	57	89	4	4	14	100			

Table 5. Error Matrix and Summary Statistics for the Multiple-Date Landsat TM Classification

	Observed Land Cover									
	W	WS	WF	UF	UA	UR	WA	Row Total	%Correct	%Commission
Water	**17**	1	2	0	0	0	0	20	85	15
Wetland Shrub	1	**9**	6	1	2	0	1	20	45	55
Wetland Forest	0	7	**39**	3	1	0	0	50	78	22
Upland Forest	1	1	5	**42**	1	0	0	50	84	16
Upland Agriculture	0	2	1	1	**92**	3	1	100	92	8
Urban	1	0	0	0	0	**19**	0	20	95	5
Wetland Agriculture	0	1	1	0	3	0	**15**	20	75	25
Column Total	20	21	54	47	99	22	17	$n = 280$	Overall Accuracy 233/280 = 83%	$\hat{K} = 0.79$
% Omission	15	57	28	11	7	14	12			

Table 6. Error Matrix and Summary Statistics for the Single-Date Landsat TM Classification after Merging the Wetland Forest and Shrubs Classes

	Observed Land Cover						Row Total		%
	W	WW	UF	UA	UR	WA		% Correct	Commission
Water	**17**	3	0	0	0	0	20	85	15
Woody Wetland	1	**17**	1	2	0	1	22	77	23
Upland Forest	1	50	**45**	2	0	0	98	46	54
Upland Agriculture	0	5	1	**95**	3	16	120	79	21
Urban	1	0	0	0	**19**	0	20	95	5
Wetland Agriculture	0	0	0	0	0	**0**	0	0	0
Column Total	20	75	47	99	22	17	$n = 280$	Overall Accuracy 193/280 = 69%	$\hat{K} = 0.59$
% Omission	15	77	4	4	14	100			

Table 7. Error Matrix and Summary Statistics for the Multiple-Date Landsat TM Classification after Merging Wetland Forest and Shrub Classes

	Observed Land Cover								%
	W	WW	UF	UA	UR	WA	Row Total	% Correct	Commission
Water	**17**	3	0	0	0	0	20	85	15
Woody Wetland	1	**61**	4	3	0	1	70	88	13
Upland Forest	1	6	**42**	1	0	0	50	84	16
Upland Agriculture	0	3	1	**92**	3	1	100	91	8
Urban	1	0	0	0	**19**	0	20	95	5
Wetland Agriculture	0	2	0	3	0	**15**	20	75	25
Column Total	20	75	47	99	22	17	$n = 280$	Overall Accuracy 246/280 = 88%	$\hat{K} = 0.84$
% Omission	15	19	11	7	14	12			

the single- and multi-date classifications. The test statistic or Z statistic calculated from analysis of the seven-class classification matrices was 4.6 as displayed in Table 8. The Z statistic calculated for the six-class matrix was 5.8 (Table 9). Both values were greater than the threshold values of significance, 2.0 ($p = 0.95$).

A pixel-by-pixel comparison of the categorized single- and multi-date TM imagery products was conducted using a GIS-based overlay analysis technique. The products of the overlay analysis are presented in both matrix (Table 10) and graphic formats (Plate 1d). The matrix has n by n values where n is equal to the number of categories present in the categorized image file. Pixel values contained in the image file corresponded to the error matrices values. Pixels that fall along the diagonal elements of the matrix represent agreement between the TM classifications results and the validation data. Other pixel values, coinciding with off-diagonal elements of the matrix, resulted when the TM classifications results disagreed with the valida-

Table 8. Summary Table and Accuracy Comparisons for the Single- and Multiple-Date Landsat TM Classifications

	Overall Percentage Correct		KHAT (%)	
	Original	Normalized	Original	Normalized
Multi-Date	83	74	79	78
Single-Date	68	57	59	59
	Combination Multi- and Single-Date Categorization		Test Statistic 4.6*	

*Significant Difference (p = 0.05)

Table 9. Summary Table and Accuracy Comparisons for Single- and Multiple-Date Landsat TM Classifications after Merging the Wetland Forest and Shrub Classes

	Overall Percentage Correct		KHAT (%)	
	Original	Normalized	Original	Normalized
Multi-Date	88	74	84	78
Single-Date	69	57	59	59
	Combination Multi- and Single-Date Categorization		Test Statistic 5.8*	

*Significant Difference (p = 0.05)

tion data. The upland and wetland forest categories represented 96 percent of all pixels in disagreement and upland and wetland agriculture pixels represented four percent of all pixels in disagreement between the single- and multiple-date classification results. Disagreement between upland and wetland forest occurred in 17.3 percent of the study area and disagreement between upland and wetland agriculture categories occurred in 0.7 percent.

Conclusions

The classification accuracy of seasonally saturated wetlands occurring in the Mid-Atlantic temperate region of the United States was improved when information about areas with wetland hydrology was merged with the initial single-date image classification. Areas with wetland hydrology were inferred using Landsat TM imagery acquired in the spring before vegetation emerged, soon after a rainfall event, on a cloud free day, during "normal" spring hydrologic conditions. The multi-temporal wetland maps developed for the Millington 7.5-minute quadrangle provided EPA Region III wetland scientists with a valuable data source to supplement the existing FWS/NWI map that was available for the study area.

Limitations of this approach for the identification of potential jurisdictional wetlands in north temperate regions are primarily related to satellite data availability. As described above, a major element used in the mapping of jurisdictional wetlands is the existence of saturated, flooded, or ponding for a long enough duration during the growing season to develop characteristic wetland soil conditions. In this study, we documented the occurrence of surface water innundation during the onset of the growing season. However, due to the lack of available imagery, we were unable to measure the duration of the inundation period. This lack of data availability is due to two factors: (1) low revisit frequency (16-days) of a single Landsat satellite, and (2) past policies to collect data only upon request to purchase. To provide adequate data availability to monitor wetland conditions from space over the majority of the conterminous United States, a constellation of Landsat TM type sensors would be required to provide adequate repeat frequency to capture seasonal dynamics associated with wetland hydrologic processes. Additionally, a policy of continual data collection over the United States would be required to provide a sufficient data archive to support routine wetland monitoring.

Additional limitations to satellite-based wetland identifications are predicated on the sensor's spatial resolution, which is directly correlated to resultant MMU capabilities. Consideration of these relationships must be evaluated commensurate with specific mapping requirements for the monitoring of jurisdictional wetlands to determine the potential application of a particular sensor system. For example, Landsat 5 TM data used in this study had a 30-meter pixel resolution and was able to support an MMU of approximately 0.8 hectares. However, with the successful deployment of the SPOT4 satellite equipped with the enhanced multispectral shortwave infra-red (SWIR) detector operating at a 20-meter pixel resolution, the capability currently exists to obtain MMUs of approximately 0.4 hectares. An additional consideration is the relationship between increased mapping resolution and cost. Typically, costs increase roughly proportionate to increases in mapping resolution (Falkner, 1994; Lyon *et al.*, 1995).

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Table 10. Matrix Indicating Agreement Between the Single- and Multiple-Date Landsat TM Classification Results

	Multiple Date Categorization Results							
	W	WS	WF	UF	UA	UR	WA	
Single Date Categorization Results	Water	**5325**	0	0	0	0	0	0
	Wetland Shrubs	0	**2264**	0	0	0	0	0
	Wetland Forest	3	12	**5185**	69	63	8	8
	Upland Forest	0	0	32390	**27636**	0	0	0
	Upland Agriculture	0	0	09	0	**110232**	0	1310
	Urban	0	0	0	0	0	**2032**	0
	Wetland Agriculture	0	0	0	0	0	0	**0**

Total percent agreement between single- and multi-date categorizations - 82%
Total percent disagreement between single- and multi-date categorizations - 18%
Percent disagreement related to upland and wetland forests - 96%
Percent disagreement related to upland and wetland agriculture - 4%

Agency's programmatic review and has been approved for publication. Mention of any trade names or commercial products does not constitute endorsement or recommendation for use.

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Notice to all ASPRS Members

Within the past month ASPRS members received a premium notice from the New York Life Insurance Company regarding term life insurance coverage that was provided to all ASPRS members free of charge over the past year. The premium notice looked like an invoice and asked for payment due by October 1st to continue the plan. Both the staff at ASPRS and Seabury & Smith, the company administering the plan, received calls from ASPRS members who were concerned that they had not explicitly asked for the insurance coverage and were confused about having to pay for something they did not request. Seabury & Smith acknowledged that the solicitation was poorly designed, agreed to issue a letter of clarification and apology, and is in the process of redesigning future promotions.

ASPRS members are not obligated to sign up for the term life insurance coverage offered. If you inadvertanly paid the invoice but do not want the coverage, you should contact Seabury & Smith's Customer Service Department at 1-800-424-9883 and they will refund your payment. ASPRS regrets any misunderstanding the solicitation may have caused.

PLEASE NOTE: all ASPRS members in good standing, who were members during the year of complimentary insurance coverage, were covered for $15,000. If any member died during that time, their beneficiaries are entitled to collect the $15,000 and should call the number above. We know of several members who recently passed away whose beneficiaries are entitled to the coverage.