

**ASSESSMENT OF REMOTE SENSING/GIS TECHNOLOGIES
TO IMPROVE NATIONAL WETLANDS INVENTORY MAPS**

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ABSTRACT

The National Wetlands Inventory (NWI) produces two very different kinds of information through remote sensing. First, detailed wetland maps are produced to support site-specific decisions. Secondly, national statistics on the current status and trends of wetlands are developed to provide information supporting the development or alteration of Federal programs and policies. The national scope and required level of detail dictated that a remote sensing tool, combined with field work, be used to conduct the project. High altitude aerial photography and satellite imagery were investigated as possible data sources. The results showed that high altitude color infrared photography provided the spectral and spatial resolution needed to obtain the required classification accuracy. The identification of temporarily and certain seasonally flooded forested wetlands remains problematic. Medium- to high-resolution multiband satellite and airborne imagery of visible, near-infrared, mid-infrared, thermal, passive microwave, and radar spectral regions were investigated using advanced GIS software packages to solve this problem.

BACKGROUND

The National Wetlands Inventory of the U.S. Fish and Wildlife Service was developed to generate information on the characteristics, extent, and status of the Nation's wetlands and deepwater habitats (Wilen and Bates 1995). The Emergency Wetlands Resources Act (16 U.S.C. 3931), as amended by P.L. 102-440, requires the National Wetlands Inventory to complete maps for the conterminous United States by September 30, 1998; to update the report on wetlands status and trends on a 10-year cycle; to produce wetland maps of Alaska by September 30, 2000; to produce a digital database for the United States by September 30, 2004; and to archive and make final maps and digitized data available for distribution.

MAPPING

The National Wetlands Inventory has produced (final and draft) maps for 87 percent of the conterminous United States and 29.5 percent of Alaska. The current budget will allow for mapping only 1 percent each year. The mandated (1998) date for completion of mapping wetlands of the lower 48 States will not

be met until at least 2011. The current budget will likewise allow for mapping only 1 percent of Alaska each year. The mandated date (2000) for completion of mapping the wetlands of Alaska will be missed by decades.

DIGITAL DATABASE

The NWI has completed 24 percent of the digital database. Statewide databases have been built for 10 States and initiated in 5 additional States. Digitized wetland data are also available for portions of 35 other States. Continued development of a digital wetlands database will have to be on a user-pays basis. This will set back the completion date of 2004 mandated by the Emergency Wetlands Resources Act of 1986. The actual completion date cannot be estimated.

WETLANDS STATUS AND TRENDS

Map making is not the only function the National Wetlands Inventory conducts through remote sensing. The NWI has produced three reports to Congress on the Status and Trends of the Nation's wetlands. In 1990, the Service produced the latest update of the status and trends report to Congress as mandated by the Emergency Wetlands Resources Act of 1986. Future national updates are to be completed on a 10-year cycle in the years 2000, 2010, 2020, and beyond. Current funding may not allow completion of the report due to Congress in 2000.

DISTRIBUTION OF PRODUCTS

National Wetlands Inventory maps and digital data are distributed widely throughout the country and the world. The principal venues for distribution are the 32 State-run distribution centers throughout the Nation; U.S. Geological Survey centers at 1-800-USA-MAPS; the Library of Congress and the Federal Depository Library System; and most recently the NWI Home Page on the Internet. The URL address for the Home Page is: <http://www.nwi.fws.gov>.

REMOTE SENSING OF FORESTED WETLANDS*

The National Wetlands Inventory has found that leaf-off, color infrared aerial photography from the early spring is best for detecting deciduous forested wetlands. Evergreen forested wetlands are a bigger problem because dense evergreen stands of the same species can occur both in the wetlands and adjacent uplands. At times, height of the evergreen canopy may reflect a difference in wetness. Wetland evergreens may be somewhat reduced in height. Wet evergreens may show signs of chlorosis due to water stress. Saturated soils or understory wetland signatures may be evident in canopy openings. The photointerpreter uses landscape and topographic position, soils information, and extensive field work to identify subtle photo signatures of evergreen and the drier deciduous forested wetlands.

*A detailed discussion on the use of high-altitude aerial photography for inventorying forested wetlands in the United States is found in (Tiner 1990).

The problem is further compounded by altered hydrology. Dams, levees, channelization projects, failed drainage, and stream-water diversions often prevent or impair normal seasonal flooding. Photointerpreters must determine whether the hydrology has been altered to the extent that the area is no longer a wetland. If an area no longer has wetland hydrology, it is a historic wetland and not mapped. If the water level has been artificially lowered, but it maintains sufficient hydrology to be classified as wetland, it is given the special modifier of Partly Drained (Cowardin et al. 1979). Generally, the modifier is only applied if there is a visible system of ditches or channels. In the southern United States, wetlands may be used for pine plantations. Some of these wetlands are effectively drained, others partly drained, and others undrained. Separating former wetlands that have been effectively drained and are no longer mapped from those that have been partly drained is often problematic.

Some types of evergreen forested wetlands and temporarily flooded deciduous forested wetlands are difficult to identify even in the field. It can require extensive soil sampling to determine the limits of hydric soils. Despite the best efforts of photointerpreters, often only general wetland boundaries with omission errors can be produced. Through remote sensing the National Wetland Inventory has identified 51.7 million acres of forested wetlands or approximately 2.6 percent of the surface of the conterminous United States (Dahl and Johnson 1991). Nearly half of the wetlands are forested. The extent of the omission errors has not been estimated. Additional details on remote sensing of wetlands are provided in Wilen and Pywell (1992) and Wilen and Bates (1995).

INCREASING THE SCALE OF AERIAL PHOTOGRAPHY

Two important studies address this topic (Tiner and Smith 1992 and MacConnell et al. 1992). Tiner and Smith (1992) investigated scales from 1:58,000 to 1:12,000. MacConnell et al. investigated scales from 1:58,000 to 1:4,800. The larger the scale of the photography, the larger the area of the wetland signature on the photograph and the larger the canopy openings that allow the photointerpreter to see more of the saturated soil or understory wetland vegetation (Figure 1). The larger the scale the greater the stereoscopic exaggeration and thus the better the view the interpreter has of landscape and topographic position.

Generally, with increasing photo scale, wetland/upland boundaries are more refined and distinct, smaller polygons are identified, and forested wetlands are easier to identify but are still difficult. Forested wetland/upland boundaries are easier to delineate at 1:12,000 than 1:5,760 photography because, at 1:5,760 and larger scales the photointerpreter could not see the forested wetland for the trees. At 1:12,000 the interpreter was able to see the forested wetland boundary and not draw the boundary line on a tree-to-tree basis (MacConnell et al. 1992).

The amount of effort required to produce a standard National Wetlands Inventory map increases dramatically with increased scale (Table 1). The second consideration is how much of the increased detail can be effectively displayed at a scale of

the standard NWI map which is 1:24,000 (see Figure 1). Lastly, and most importantly, forest wetlands larger, and in some cases much larger, than the minimum mapping unit are still not detected. The problem with identifying forested wetlands is spectral resolution, not spatial resolution. Increasing the scale of photographs only increases the spatial resolution.

Figure 1. Pen width and relative sizes of polygons at different scales of photography (MacConnell et al. 1992)

SCALE Representative Fraction	Verbal	PEN LINE WIDTH ON THE GROUND	
		3x0 (.25mm)	4x0 (.18mm)*
1:4,800	1"=400'	4.0'	2.8'
1:7,200	1"=600'	6.0'	4.2'
1:12,000	1"=1,000'	10.0'	7.0'
1:24,000	1"=2,000'	20.0'	14.0'
1:40,000	1"=3,333'	33.3'	23.3'
1:58,000	1"=4,833'	48.3'	33.8'

*Practical limit of fine pen point size for photo annotation which is wide enough on the larger scale photos to be easily discernible for transfer to base maps. 4x0 pens are normally used by NWI on 1:58,000 photos.

SCALE	1 ACRE	1/2 ACRE	1/4 ACRE
1:4800			
1:7200			
1:12000			
1:24000			
1:40000			
1:58000			

Table 1. Summary of labor required at various steps (excluding ground-truthing and Regional Quality Control) to prepare a large-scale wetland map from different scales of photography. The symbol "x" is used to indicate ratios within a particular step, so 2x takes twice as much time as "x". Hours of labor for "x" in each step is designated in parentheses (Tiner and Smith 1992).

Step	Scale of Aerial Photography (# photos)			
	1:58K (3)	1:36K (6)	1:24K (12)	1:12K (42)
Data Preparation	0.5x	x (1 hr.)	2x	7x
Photointerpretation	0.9x	x (10.25 hrs.)	2.1x	4.4x
Quality Control (National PIQC)	x	x (0.5 hrs.)	2.5x	6x
Map Preparation	0.5x	x (28 hrs.)	2.2x	3.3x

EVALUATION OF OTHER SENSORS

As early as 1979, the National Wetlands Inventory evaluated 80-meter resolution multispectral scanner (MSS) data for its value in identifying and mapping wetlands, and over the years has looked at the new sensors as they have come on line.

President's Domestic Policy Council's Wetlands Task Force

The President's Wetlands Task Force requested that the Federal Geographic Data Committee's Wetland Subcommittee report on the application of satellite data for mapping and monitoring of wetlands. On January 14 and 15, 1992, the subcommittee held a meeting to discuss the current application of satellite data for mapping and monitoring of wetlands. The subcommittee invited top-level technical experts from the following organizations to address a preset list of questions and describe their experiences: Earth Observation Satellite Company; SPOT Image Corporation; Ducks Unlimited; U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory; National Oceanic and Atmospheric Administration, Coast Watch, Change Analysis Program; Earth Satellite Corporation; U.S. Geological Survey, Earth Resources Observation System Data Center; and Maryland Department of Natural Resources.

The Wetlands Subcommittee reported that the detail and reliability of information derived from satellite data have steadily improved. These improvements include advancements in spatial and spectral resolution, georeferencing, and digital image processing techniques, along with growing experience using satellite data. Significant strides have been made in integrating ancillary data, such as soils and digital elevation models, into the classification of satellite data. This integration is dependent upon the use of geographic

information system (GIS) technology. Stream gauging data and rainfall data are now being used to select the best scenes for wetland identification. Even with these improvements, satellite data can not match the accuracy of areal extent, classification detail, or reliability that can be extracted from conventional aerial photography using manual photo-interpretation techniques, such as those used by the U.S. Fish and Wildlife Service's National Wetlands Inventory Project. However, for some regions, satellite remote sensing may be the most cost-effective means for conducting reconnaissance wetland surveys.

The power of satellite imagery lies in its ability to be easily integrated with all other sources of data in a GIS, contributing to the accuracy of the GIS. The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) believes that satellite technology can help to classify certain administrative classes of wetlands legislated by the Farm Bills of 1985, 1990, and 1996. Many other resource managers have complained that, in practical application, the promise of space-based remote sensing has not measured up to National Wetlands Inventory's actual performance. The subcommittee believes satellite data, when used in conjunction with NWI digital data produced through the use of aerial photography, can provide a tool for monitoring water levels in wetlands and monitoring the cover change of adjacent uplands. Synergistic effects created by combining both satellite data and NWI digital data have greater value than using either data source alone. Such data sets have the potential to be synoptic and accurate (Federal Geographic Data Committee 1992).

The President's Wetlands Task Force also directed the Wetlands Subcommittee of the Federal Geographic Data Committee to complete reconciliation and integration of all Federal agency wetland inventory activities. The Federal Geographic Data Committee's Wetlands Subcommittee developed a strategic interagency approach (FGDC, Wetlands Subcommittee 1994).

A working group was formed with representatives from the U.S. Department of the Interior (U.S. Fish and Wildlife Service (FWS) and U.S. Geological Survey (USGS)), the U.S. Department of Agriculture (Natural Resources Conservation Service (NRCS)), the U.S. Department of Commerce (National Oceanic and Atmospheric Administration (NOAA)), the Environmental Protection Agency, and the Maryland Department of Natural Resources.

Pilot Study. The working group began a pilot study to better understand the issues and problems associated with the data comparison task. Wicomico County, Maryland, was selected as the pilot because: (1) wetland data and other spatial data in digital form were available from the various government agencies, (2) the county's proximity to the Washington, D.C., area facilitated field analysis where necessary, and (3) the county has an abundance of forested wetlands, which are generally recognized as the most difficult wetland type to map.

Description of Wicomico County, Maryland.* The study area is on the Atlantic Coastal Plain of Maryland's eastern shore. Lithologically, this part of the Coastal Plain is composed of marine units of varying thicknesses. Clay, sand, and shells are the major deposits. Characteristically, the surface is of low elevation, usually between 0 and 25 feet. The low elevation and the broad smoothness of the region cause the streams to have a gentle gradient and the stream incision is minimal. The amount of stream incision directly affects the level of the water table; thus, the water table is high throughout the county. The low elevation and smoothness of the land surface combined with a gentle stream gradient and high water table result in a well-developed floodplain and extensive areas of wetlands. Small changes in elevation, microtopography, or parent material will determine whether a given site is wetland or upland.

Results. The study provided clear evidence that there were significant disagreements in wetland delineation among the various government wetland data sets and that some data sets (e.g., the National Wetlands Inventory maps) had significant omission errors while other data sets had significant commission errors. It was not possible to determine the accuracy of the data sets due to the lack of a standard to measure against. It was clear that no agency had solved the problem of mapping temporarily flooded deciduous forested or evergreen forested wetlands. Everyone either overmapped or undermapped these wetland types (Shapiro 1995).

Field of Dreams

Nine data overlays for Wicomico County were assembled in a GIS (Table 2). Because the scale, content, resolution, format, and collection methods for each of the data sets varied, the U.S. Geological Survey designed a GIS analysis interface (Sechrist 1995). It allowed the operator to view, manipulate and compare the data sets.

Table 2. Wicomico County Data Overlays

1. USGS, 1:100,000-scale digital line graphs
2. USGS, 1:250,000-scale land use/cover vector data
3. FWS, 1:24,000-scale wetland vector data
4. NOAA, 30-meter resolution raster wetland and upland data
5. NRCS, Natural Resources Inventory, point wetland and upland data
6. NRCS, 1:24,000-scale raster swampbuster wetland
7. NRCS, 1:20,000-scale soil vector data
8. MD, Department of Natural Resources (DNR), 4-foot resolution color infrared digital orthophoto quarter quadrangle images (DOQQ)
9. MD (DNR), wetland vector data registered to 1:12,000 scale DOQQ

*This description of Wicomico County, Maryland, is from an unpublished paper by Tera Paul, U.S. Geological Survey.

To this data set an independent contractor provided field verified data for 130 sites. A group of agency scientists made wetland determinations at 100-foot intervals on 11 transects across wetland and upland boundaries. Lastly, 10 wetland/upland boundaries were established in the field and surveyed. Groups of five ground water wells were placed across each of these surveyed wetland/upland boundary lines and their positions were also surveyed.

The problems all parties had identifying forested wetlands and the amount of data collected and entered into a GIS result in a kind of "field of dreams" that attracted several other groups to attack the problem of mapping forested wetlands with a variety of sensors.

Passive Airborne Microwave

The emission of radiation from the Earth's surface at microwave wavelengths is dependent on many environmental factors, including soil temperature, surface roughness, vegetation water content, soil water content, bulk density and soil texture. It is possible to estimate soil moisture content and water table depth by measuring the intensity of emitted microwave radiation in different wavelengths. Clouds and rain are the main sources of interference at wavelengths shorter than 5 mm. Radar, TV installations, and galactic and ionospheric radiation interfere with reception of wavelengths over 30 cm. Between those wavelengths, radiation is most sensitive to the water content in the soil.

To predict those variables from emitted radiation, it is necessary to collect data from 2 or 3 radiometers operating at different wavelengths between 0.5 and 30 cm. The portion of soil water content indicated by microwave radiation variability is the free water content, or water that is not bound, chemically or physically, to the soil particles. Free water is expressed as grams per cubic centimeter, which is roughly equivalent to percent of total volume (assuming a density of 1 g/cc). Saturation occurs when all the free space in the soil is occupied by water. Emitted microwave radiation was measured from an aircraft using radiometers equipped with antennas operating at different wavelengths. Two antennae (18 cm and 6 cm) were mounted externally to the bottom of the aircraft.

The tests conducted by Photo Science and Geoinformatic were sufficient to prove the technical feasibility of using airborne microwave radiometry for mapping soil moisture characteristics. The results of the tests, with respect to the potential of the technology for wetlands mapping, were both encouraging and disappointing. The spatial resolution of the data is clearly not sufficient for this approach to provide improvements over other existing methods of wetlands mapping for general inventory purposes. However, there is enough empirical correlation between the soil moisture characteristics as interpreted from the radiometer data, known wetlands and the orthophoto image to suggest that there may be applications for the technology to meet certain specific mapping purposes (PhotoScience 1993). The Department of

Transportation is investigating its use to attempt to separate uplands from areas that contain wetlands or potentially have wetlands.

Airborne Terrestrial Applications Sensor (ATLAS), Airborne Synthetic Aperture Radar (AirSAR), and Shuttle Imaging Radar - C (SIR-C)*

NASA's Commercial Remote Sensing Program in cooperation with the U.S. Environmental Protection Agency, U.S. Geological Survey, U.S. Fish and Wildlife Service, EarthSat Corporation, and the University of Colorado at Colorado Springs undertook a project to verify and validate the utility of commercially available satellite and airborne imagery processing techniques to accomplish less-expensive, more-reliable wetland maps. The project team had all the ancillary data collected for the earlier study plus 1:8,000 scale color infrared photography acquired over the study area. The remote sensing data collected is detailed in Table 3.

Table 3. Remote sensing data types used in wetland classification analysis

Test Data	Date of Acquisition	Total/Kinds of Channels	Spatial Resolution
ATLAS Daytime	4/5/95	15 channels in VIS, NIR, MIR, TIR ¹	2.5 m
ATLAS Pre-Dawn	4/6/95	15 channels in VIS, NIR, MIR, TIR	2.5 m
SIR-C	4/12/94	8 channels 4 polarities C and L bands	12.5 m
AirSAR	6/2/95	12 channels 4 polarities C, L, and P bands	9.0 m

¹VIS, NIR, MIR, and TIR refer to visible, near infrared, mid-infrared, and thermal infrared spectral regions.

The characteristics of the SIR-C and AirSAR data are provided in Table 4. A description of the multi-sensor data stack is presented in Table 5.

*This description of the project is derived from an unpublished paper entitled "An Assessment of Remote Sensing/GIS Technologies for Delineation of Wetlands" prepared by the Commercial Remote Sensing Program Office of the National Aeronautics and Space Administration and Lockheed Stennis Operations both located at the John C. Stennis Space Center, Mississippi.

Table 4. Characteristics of radar (SIR-C and AirSAR) data

	SIR-C	AirSAR
Acquisition date	4/12/1994	6/2/1995
Projection	Ground range	Ground range
Wavelength (cm)	C band (5.7 cm) L band (24 cm) X band (3 m) ¹	C band (5.7 cm) L band (24 cm) P band (68 cm)
Line spacing (m)	12.5	8.23
Pixel spacing (m)	12.5	8.23
Incidence angle(°)	24.53	21.34
Polarizations	HH, HV, VH, VV ²	HH, HV, VH, VV

¹X band was acquired with C and L bands but not included in the data set from JPL.

²HH, HV, VH, and VV refer to horizontal send and receive, horizontal send and vertical receive, vertical send and horizontal receive, and vertical send and receive.

Table 5. Description of multi-sensor data stack

Number	Description	Center Wavelength (µm)
1	ATLAS band 1 (day mission, green band)	0.466 µm
2	ATLAS band 4 (day mission, red band)	0.637 µm
3	ATLAS band 6 (day mission, near infrared band)	0.773 µm
4	ATLAS band 11 (day mission, thermal band)	9.2 µm
5	ATLAS band 12 (day mission, thermal band)	9.9 µm
6	ATLAS band 11 (night mission, thermal band)	9.2 µm
7	ATLAS band 12 (night mission, thermal band)	9.9 µm
8	AirSAR PHH	68 cm
9	AirSAR PHV	68 cm
10	AirSAR PVV	68 cm
11	AirSAR LHH	24 cm
12	AirSAR CTP	5.7 cm
13	ATLAS day-night thermal difference	9.9 µm

Analyses. Data analysis was divided into two major components: delineation of wetland cover types and identification of general wetland boundaries. Traditional remote sensing classification algorithms (supervised and unsupervised) and neural network analyses were applied to the data sets to study cover type and wetness mapping capabilities of AirSAR, ATLAS, and SIR-C data. In addition, two alternative techniques (cluster busting and a hybrid analysis) were conducted. AirSAR, SIR-C, plus ATLAS visible, near infrared, and thermal (daytime and predawn) data were used as the primary input for the wetness analysis, while cover type analysis was performed on the multisensor data stack, ATLAS visible through near infrared, AIRSAR and SIR-C data.

Conclusions. The project yielded some encouraging results, particularly the AirSAR imagery, but the goal of producing more reliable wetland maps was not achieved. AirSAR was the best overall data source for detecting wetland versus upland areas. It is anticipated that a three component scattering model (surface scatter, canopy scatter, and double bounce scatter) could be helpful in reducing wetland omission errors by separating clearcut wetlands from uplands (Freeman and Durden 1992). Results suggest that ATLAS 2.5-meter spatial resolution tends to measure reflectance/radiance from individual trees instead of from larger habitat patches. The resampling of the ATLAS data from 2.5 to 9 meters enabled mixed cover types to be more visually apparent on color infrared composite image displays. Suggesting again that spectral not spatial resolution is the limiting factor in remotely sensing forested wetlands.

Results of cluster separability analysis of the multisensor ATLAS/AirSAR data stack suggest that AirSAR data contributes more to spectral separability than ATLAS day and pre-dawn data. Comparison of ATLAS daytime thermal and pre-dawn thermal data types indicates daytime thermal data tended to have increased separability of wetness over pre-dawn thermal data. Neural network classifications corroborated this result. Neural network approach to wetness classification yielded similar results compared with traditional unsupervised classification techniques. Additional research is being conducted at the University of Colorado, Colorado Springs, on the use of neural nets on these data sets.

Wetland/upland classification analyses performed on AirSAR, SIR-C, ATLAS daytime thermal, and ATLAS pre-dawn thermal data layers indicate these data types have potential for identifying wetness in vegetated cover but do not contain the information content needed to discriminate wetland cover types to the level of detail used by the National Wetlands Inventory. However, both the ATLAS daytime and AirSAR data appear to have sufficient information to derive general land cover maps suitable for updating NWI cover-type change. Other studies have shown the promise of using satellites to monitor changes and losses of wetlands (EarthSat 1993).

National Cooperative Highway Research Board (NCHRB)

The NCHRB has funded a project entitled "Remote Sensing and Other Technologies for the Identification and Classification of Wetlands." The contractor for the project is Normandeau Associates. The goal is to define methodologies for efficiently and effectively identifying, classifying, and locating wetlands within potential highway corridors and

alignments beyond the detail and accuracy of National Wetlands Inventory maps. The problem is that highway corridors and alignments have been selected based on National Wetlands Inventory maps to find after field work that some forested wetlands were unmapped.

In one case, after field investigations it was determined that an unselected corridor in fact had fewer wetlands than the one selected using National Wetlands Inventory maps. The contractor expects an evaluation of new technologies and geographical information systems in combination with other existing information resources will be required. The contractor has visited the Wicomico field of dreams and is aware of what has already been investigated.

Additional Studies

Two additional studies are underway; the first is using very high resolution digitized multitemporal color infrared photography and the second is using National Technical Means.

DISCUSSION

Why can't we find a solution to the problem of photointerpreting some types of forested wetlands? Radiometric data are often hard to evaluate because there are numerous variables that prevent correlation between radiometric response and ground phenomena. They include the amount of energy reaching the sensor, illumination of the object being sensed, atmospheric variables, differences in reflectance due to season and growth stage of vegetation, sensor ability to capture and record the data, etc.

Remote sensing specialists can deal with these problems, but the photointerpreters have misled those trying to help us by constantly referring to "signatures" in photointerpretation. I have used the term in this paper, but the term "signature" is misleading. It implies a distinctive mark that is unique and consistent. Wetland signatures on color infrared film are not unique or consistent. Signatures vary according to time of day (affecting shadow and glare), season (including degree of shadow, endless stages of leaf-out and aging, short-term and long-term weather patterns, combinations of weather patterns, snow cover, ice cover and water cover that is sometimes so extensive or deep early in the year, that you can't delineate wetlands), emulsion (which can be predominantly blue, green, pink, red, or purple in tone or the tone might be washed out or too dark). Photointerpreters must deal with these variations in signatures. It takes expertise, experience, and the power of reasoning to transcend these variations. If we can't solve it, what can we do to reduce the problem?

- o Film development and duplication are two areas where there appears to be potential for major technological advancements. Often there is a significant difference between whether the duplicated photos are processed as a single print or as an entire roll. It appears that color infrared film and duplicates can be developed to enhance or mask wetlands. The reasons for the problems introduced in the development and duplication process are not fully understood. Important insights into some of these problems are provided in Hershey and Befort (1995).

- o Soils maps are an important source of collateral data for mapping wetlands. Checking for hydric soils is presently a cumbersome and time-consuming process. A product that relates soils data to the USGS quad map would save time in the photointerpretation process. The photointerpreter could easily relate the land-surface form features (contours) in relation to the hydric soils units. Even having the normal NRCS soils map in a quad style format would be helpful.
- o Due to the number of variables, subtleties and exceptions that go into every photointerpreted delineation and classification, it appears that any solution must involve a human. The solution needs to be computer assisted where the computer assists the human.
- o Surface water often blends in with shadows on color infrared film. A technique needs to be developed to separate shadows from open water. On the edges of color infrared photographs you can see the glare of the sun as it is reflected off water in open wetlands. This same phenomenon can be experienced from an airplane. AirSAR L band radar with a HH (horizontal send and receive) polarization revealed drainage patterns due to the strong double-bounce return. Spectral reflectance from the smooth, highly reflective water surface is bounced back toward the receiver by vertically oriented trunks. A sensor that takes advantage of these phenomena would be useful for identifying flooded forested wetlands.

CONCLUSION

The problem of photointerpreting certain types of forested wetlands has not been solved. We have learned that the problem is spectral not spatial resolution. In fact, at some point too much spatial resolution worsens the problem. Potential new data sources such as the Airborne Terrestrial Applications Sensor (ATLAS), Airborne Synthetic Aperture Radar (AirSAR), Shuttle Imaging Radar-C (SIR-C), Airborne Multisensor Pod System (AMPS) and the civilian use of National Technical Means are becoming increasingly accessible for evaluation. In addition, several new high resolution remote sensing satellites are just over the horizon. The full potential of the existing sensors has not been adequately explored. A Geographic Information System (GIS) provides the tools to georeference, quantitatively compare, analyze, visualize, tabulate, and produce composite maps necessary for evaluation. Without a GIS, the tasks of quantitatively comparing various maps and remote sensing data would be impractical. Before the remote sensing satellite builders can help us solve our problems, we must learn to be able to clearly communicate with them. Terms like photo signatures cause confusion. Signature implies something distinctive, unique and consistent and, in reality, photo signatures are not. They vary according to a multitude of variables already discussed.

Our investigations have shown that wetland mapping omission errors result from photointerpreters not field checking what appear to be apparent upland "signatures." Wetland "signatures" and confusing "signatures" are investigated but apparently obvious upland "signatures" are ignored. The lesson is that some percentage of the areas with a potential wetland landscape and topographic positions need to be field

checked even though they have what appears to be an obvious upland "signature." Note how many times I have used the misleading term "signature." In order to assess accuracy, you need a standard to compare against. Comparing data sets do not result in an accuracy assessment. They result in a comparison.

A systematic analysis of existing data sources needs to be conducted before their full potential can be appreciated. Testing should be undertaken to determine the most effective resolution for various applications. Builders of satellites must be careful that they do not collect data at such fine resolutions, e.g., one or two meters, that it adds to rather than reduces classification confusion when automated classification approaches are utilized.

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