In cooperation with the Michigan Army National Guard's Fort Custer Training Center, Battle Creek, Michigan

Wetland Delineation with IKONOS High-Resolution Satellite Imagery, Fort Custer Training Center, Battle Creek, Michigan, 2005

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Cover Photograph. Wetlands at Fort Custer Training Center, Battle Creek, Michigan. (Photograph by L.M. Fuller, U.S. Geological Survey, May 2005).

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Area	
acre	4,047	square meter (m^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Length	
meter (m)	3.281	foot (ft)

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Abstract

The Michigan Army National Guard's Fort Custer Training Center (FCTC) in Battle Creek, Mich., has the responsibility to protect wetland resources on the training grounds while providing training opportunities, and for future development planning at the facility. The National Wetlands Inventory (NWI) data have been the primary wetland-boundary resource, but a check on scale and accuracy of the wetland boundary information for the Fort Custer Training Center was needed. In cooperation with the FCTC, the U.S. Geological Survey (USGS) used an early spring IKONOS pan-sharpened satellite image to delineate the wetlands and create a more accurate wetland map for the FCTC. The USGS tested automated approaches (supervised and unsupervised classifications) to identify the wetland areas from the IKONOS satellite image, but the automated approaches alone did not yield accurate results. To ensure accurate wetland boundaries, the final wetland map was manually digitized on the basis of the automated supervised and unsupervised classifications, in combination with NWI data, field verifications, and visual interpretation of the IKONOS satellite image. The final wetland areas digitized from the IKONOS satellite imagery were similar to those in NWI; however, the wetland boundaries differed in some areas, a few wetlands mapped on the NWI were determined not to be wetlands from the IKONOS image and field verification, and additional previously unmapped wetlands not recognized by the NWI were identified from the IKONOS image.

Introduction

The Michigan Army National Guard's Fort Custer Training Center (FCTC) has the responsibility to protect wetland resources on the training grounds while providing training opportunities for National Guard units. The FCTC environmental managers have developed a Natural Resources Management Plan (NRMP) based on the National Wetlands Inventory (NWI) to aid in the protection of the center's wetlands. Various studies, including onsite anecdotal investigations, have indicated possible inaccuracies in the NWI wetland boundaries and omission of some small wetlands in the NWI database.

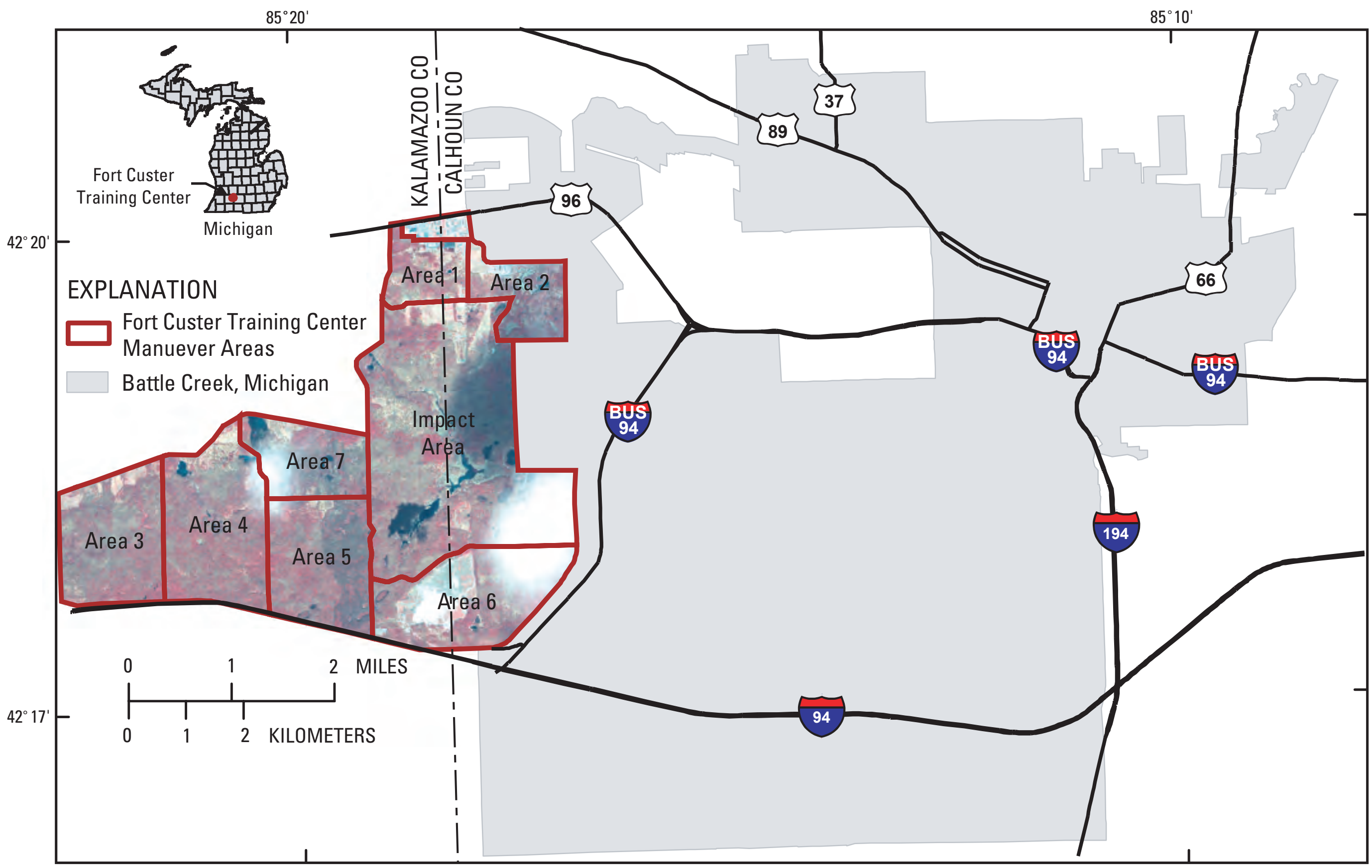
The U.S. Geological Survey (USGS), in cooperation with FCTC, acquired IKONOS satellite imagery (commercial satellite owned by Space Imaging *http://www.spaceimaging.com/products/ikonos/index.htm*) and analyzed it by means of automated supervised and unsupervised classification techniques. Although the study area was relatively small, and a manual digitizing approach was possible, an automated technique was sought because field-based wetland delineation is labor intensive and costly, whereas a remote sensing approach using high-resolution multispectral satellite imagery can be more cost-and labor-efficient. The purpose of this study was to test whether automated classification techniques (supervised and unsupervised classifications) by themselves were adequate to classify wetland features at FCTC by use of IKONOS satellite imagery. If these techniques produced accurate results, they could potentially be applied to other study areas. Ancillary data also were available to serve as reference and verification for the wetland areas, including the NWI, field Global Positioning System (GPS) verification data, and manual classification techniques. IKONOS multispectral (visible and near infrared) pan-sharpened satellite imagery was used to differentiate the wetland and upland areas. Results of this study are reported herein.

Study Area

The FCTC covers approximately 7,570 acres in southwestern Michigan (Kalamazoo and Calhoun Counties) west of the city of Battle Creek. The FCTC provides training facilities for National Guard units from Michigan and other states and includes training in the operation of military support and combat vehicles. Most of the FCTC property is forested but interspersed with some clearings and prairie areas (Maneuver Areas 1-7); ranges for firearms training are within an Impact Area, and a small section with buildings and barracks is in the northern part of FCTC (fig. 1). Wetland areas are present throughout the study area but are more concentrated in the eastern part of the property, as shown in the NWI data (fig. 2).

Background

The NWI was begun by the U.S. Fish and Wildlife Service in 1977, and it continues to date (2006) according to the NWI metadata. Wetlands and deepwater habitats were digitized from aerial imagery for use as overlays for the U.S. Geological Survey topographic maps (U.S. Fish and Wildlife Service, 2004). The wetlands and deepwater habitats follow the definition in Cowardin and others (1979). Accuracy of the wetland-area delineations depends on the "quality of the imagery, the experience of the image analysts, the amount and quality of the collateral data, and the amount of ground truth



City boundary from the Michigan Cities Layer 2003, Michigan Geographic Framework
Roadlines from the All Roads layer 2003, Michigan Geographic Framework

Figure 1. Fort Custer Training Center Battle Creek, Michigan, shown with an April 25, 2005 IKONOS satellite image.

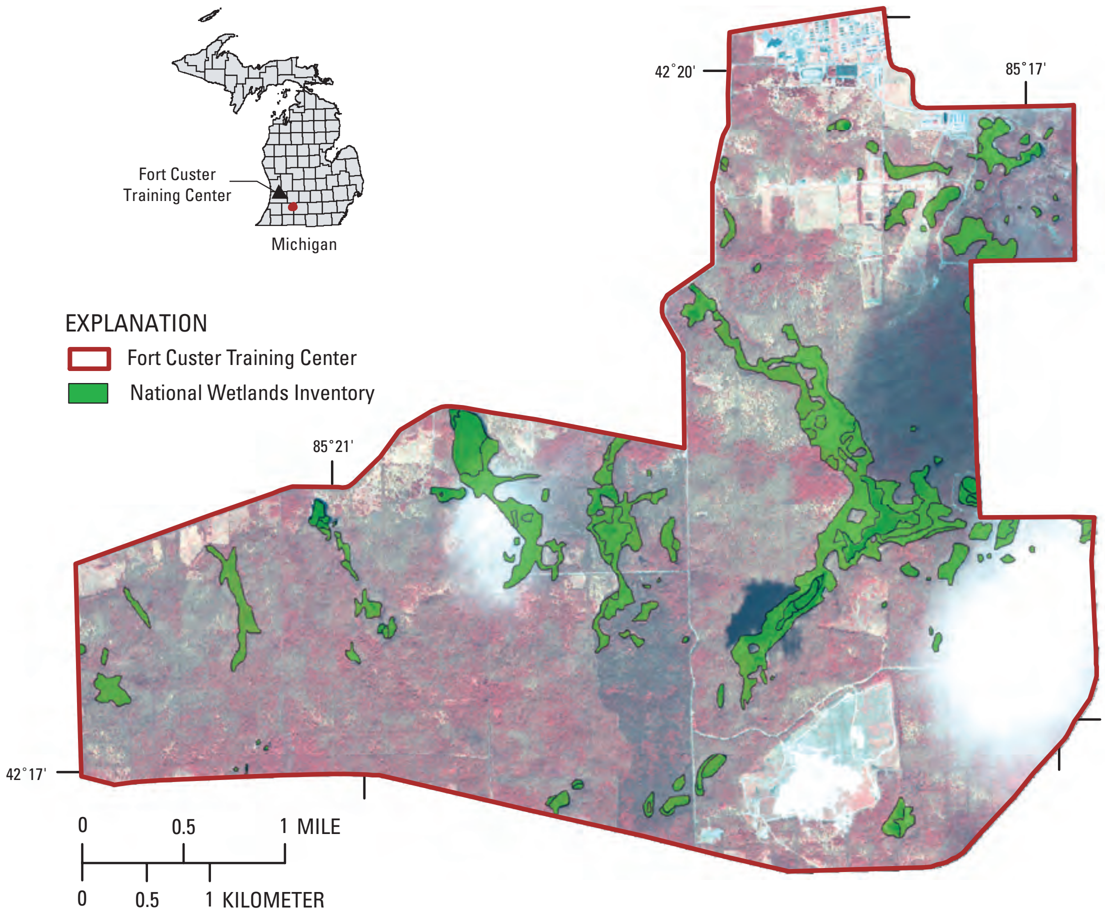


Figure 2. National Wetlands Inventory wetlands shown with an IKONOS April 25, 2005 satellite image of the Fort Custer Training Center in Battle Creek, Michigan.

verification work conducted" (U.S. Fish and Wildlife Service, 2004). Downloadable NWI polygons are available with the Wetlands Mapper online at *http://wetlands.fws.gov/mapper_tool.htm.*

Ernst-Dottavio and others (1981) found that wetlands can exist as isolated small pockets within other land-cover categories. Such small wetlands can be more difficult to identify than larger, contiguous wetlands and could have been overlooked in the creation of the NWI database. A current approach to identify small wetlands and to distinguish between wetland aquatic vegetative species is to use high-resolution multispectral satellite imagery (Antunes and others, 2003; Olmanson and others, 2002). IKONOS imagery is submeter, multispectral imagery, which can be used to test methods of delineating wetlands.

Some general classification schemes used to identify land-cover types or features from satellite imagery include supervised classifications and unsupervised classifications which are both automated techniques; visual interpretation; and hybrid approaches which involve a combination of any of the classification schemes. Supervised classifications are used when the image analyst has knowledge of the study area. An analyst identifies sample training sites for various land-cover types in the satellite image, and the image is then classified by how similar the pixels in the satellite image are to the training sites. Various methods are available to help determine the similarity of the pixels to the training sites (Lillesand and Kiefer, 2000). Unsupervised classifications do not use training areas but instead group pixels into natural groupings or clusters. The analyst has the option to set the number of desired output classes and to use various clustering algorithms to determine appropriate land-cover classes (Lillesand and Kiefer, 2000). Visual interpretation involves the analyst tracing or digitizing land-cover boundaries directly on the satellite image by use of Geographic Information Systems (GIS). For this technique, the analyst needs knowledge of the study area to correctly identify and digitize land-cover boundaries.

Materials and Methods

IKONOS satellite imagery was purchased for the FCTC to create a final wetland map. Training sites were located in the field for wetland verification and were also used in the automated techniques for supervised and unsupervised classifications. All the wetlands were also digitized from the IKONOS satellite imagery using the automated techniques and the NWI wetland database as reference data. All image processing was done with Erdas Imagine 8.5 software (Leica Geosystems, 2001), and all digitizing and final map editing were done with ArcMap 9.0 software (ESRI, 2004).

IKONOS Satellite Imagery

An IKONOS satellite image of the Fort Custer study area was acquired on April 25, 2005. An image taken during the spring was needed to identify inundated areas (Jensen and others, 1984; Hodgson and others, 1987; Lunetta and Balogh, 1999). Ground-control points were collected with a Leica GS20 GPS, and were differentially corrected using a base station in Battle Creek, Mich. The IKONOS image was geometrically rectified with the ground-control points with a root mean square (RMS) error of 0.4691 m. The rectified image was pan-sharpened by use of panchromatic and multispectral images acquired for the same time and date. This process resulted in a 16-bit multispectral (visible and near infrared) satellite image with a pixel size of 0.77 m.

Training Sites

Data from six training sites at FCTC, to be used to assist in the image classification, were collected in the field during May 2005. Wetland boundaries in polygon and point format were identified using the Leica GS20 GPS unit. The field sites included three categories of wetlands: emergent, forested/shrub, and pond.

Automated Techniques

A supervised classification was used with known wetland locations to identify similar wetland features in the IKONOS image. An unsupervised classification was used to identify wetland features that might not be identified by the supervised classification. Results from each classification were used to test the effectiveness of each method.

Supervised Classification

Two supervised classifications using maximum likelihood were used in the study. The first supervised classification was done on an unedited image for the entire study area. Classes used in the training phase were water (pond), emergent wetland, forested/shrub wetland, cloud, cloud shadow, transportation, forest, crops, buildings, and bare areas. Subclasses were added to help define each class more accurately (for example, shallow water and deep water). Additional subclasses were also identified for cloud-shadow areas: water (pond), forested, and emergent wetland. This was done to create new classes that were visible within the cloud-shadow areas but that would have been confused with the same land-use types outside the cloud-shadow areas (for example, forested and forested in cloud-shadow area).

The second supervised classification was done on an edited image in which cloud and cloud-shadow areas were removed. These areas were digitized and coded to "nodata" to remove them from the IKONOS image. The same basic classes of water (pond), emergent wetland, forested/shrub wetland, transportation, forest, crops, buildings, and bare areas were used, and subclasses were added within each category as needed. Because areas of clouds and cloud shadows were removed, wetlands in those areas would not be identified. This classification was done to see whether removing the cloud and cloud shadows would improve the overall classification results for wetlands, assuming that cloud and cloud shadows could cause confusion between classes.

Unsupervised Classification

An unsupervised classification was done on the image specifying 200 classes with 25 iterations, a 0.99 confidence interval, using the principal axis, and 2 standard deviations. This classification was used to identify possible wetland areas not visually obvious on the imagery, areas not included in the NWI, or areas that had changed shape since the NWI had last been mapped.

Separation of Land-Cover Classes

Both the supervised and the unsupervised classifications were assigned wetland and other land-use classes by using the IKONOS image and the NWI wetland layer as references. Classes that were visibly wetland were classified "wetland," other land-cover classes that were clearly identifiable as nonwetland were classified "not wetland," and mixed classes, or features not identified as either wetland or not wetland, were coded "none".

A method to help determine the correct classification of "not wetland" classes is known as cluster busting (Jensen and others, 1987). For this study, the classes from the supervised classification that could not be classified were masked out and used to make a new image, and the same was done for the unsupervised image. An unsupervised classification with the same parameters previously mentioned was then done on each new image. This procedure helped separate mixed classes and reclassify those areas that were not easily identifiable in the first classification.

Manual Digitizing

The resulting supervised and unsupervised classifications and the NWI were used as references to locate wetland areas on the IKONOS image. Wetland areas were manually digitized using ArcMap 9.0. Areas that were determined to be wetland on the classified images and the NWI were digitized as "wetland" if they were visually identifiable on the IKONOS image. In addition, areas that were interpreted as wetland on the IKONOS image but not identified as wetland on the classified images or NWI were digitized. The final size and shape of the wetlands were determined from the IKONOS image, with the automated classifications, NWI maps, and GPS data as references.

Verification Process

Wetlands were verified in the field with the GPS unit to check whether mapped wetlands were present and if their boundaries were accurate. Boundaries of wetlands that were identified by the classifications or visually interpreted from the satellite imagery but were not marked as wetlands on the NWI maps were field checked for verification. Wetlands that were mapped on the NWI maps but were not determined as wetlands by the classifications or visually interpreted from the satellite imagery also were field checked. Wetlands in forested areas were field checked because interference from the tree canopy created difficulties in determining their correct boundary from the IKONOS imagery.

Effectiveness of Wetland-Delineation Approaches

The two automated techniques (supervised and unsupervised classifications) did not result in the accurate wetland boundaries that were hoped for. The supervised classification on the unedited image identified water (pond) areas very well but had difficulty identifying emergent and forested/shrub wetlands. Upland areas were often confused and mixed with the emergent and forested/shrub wetlands. The cluster-busting technique helped separate some of the mixed classes into wetland and nonwetland, but there were still too many wetland/upland mixed classes. Emergent wetlands were still mixed with upland vegetation, and forested/shrub wetlands were mixed with upland forest and shrub areas. Many of the mixed classes were in areas with cloud shadows.

The second supervised classification on the edited IKONOS image (areas with cloud and cloud shadows removed) did not solve the mixed class problem. Mixed classes of wetland and nonwetland in this second analysis were due to shadows from trees or were open areas that had similar features to emergent wetland areas. The unsupervised classifications yielded similar results. Both automated classifications returned a speckled image of wetland areas, but not all wetland areas were identified, and some areas classified as wetlands were not actually wetlands. The IKONOS 16-bit image had a lot of pixel values (65,536 possible pixel values), and the automated techniques did not classify the numerous pixel values well.

Although mixed classes resulted from both automated classifications, these approaches were useful in identifying some wetland areas not shown on the NWI maps; however, the boundaries of the wetlands had to be determined from the IKONOS imagery. In addition, 5 wetlands totaling 3.94 acres were found during visual examination of the IKONOS imagery that were not identified on the NWI maps or through the classification processes; upon field verification, these also were digitized. The final digitized map included NWI wetlands with size and shape corrections, eliminated classified wetlands from the NWI maps that were determined not to be wetlands when field checked, and incorporated new wetlands found either by the automated classifications or through visual interpretation of the satellite imagery, all of which were field verified. A comparison of the NWI and the final digitized map for the northeast part of FCTC is shown in figure 3. The final wetland map showed 739.23 acres of classified wetlands, whereas the NWI map showed 695.44 acres of wetlands. A 200 m buffer (requested by FCTC) was placed around the wetland boundaries on the final map for future wetland protection at FCTC. The final wetland map with the 200 m buffer area is shown in figure 4.

Summary and Conclusions

The Michigan Army National Guard's Fort Custer Training Center (FCTC) required a more accurate wetland map to protect wetland resources on the training grounds. Wetland maps for FCTC were created with IKONOS satellite imagery with a 0.77 m cell resolution. Supervised and unsupervised automated classifications were done on the imagery to identify wetland areas. These two methods were effective in identifying water (pond) areas but had difficulty identifying emergent and

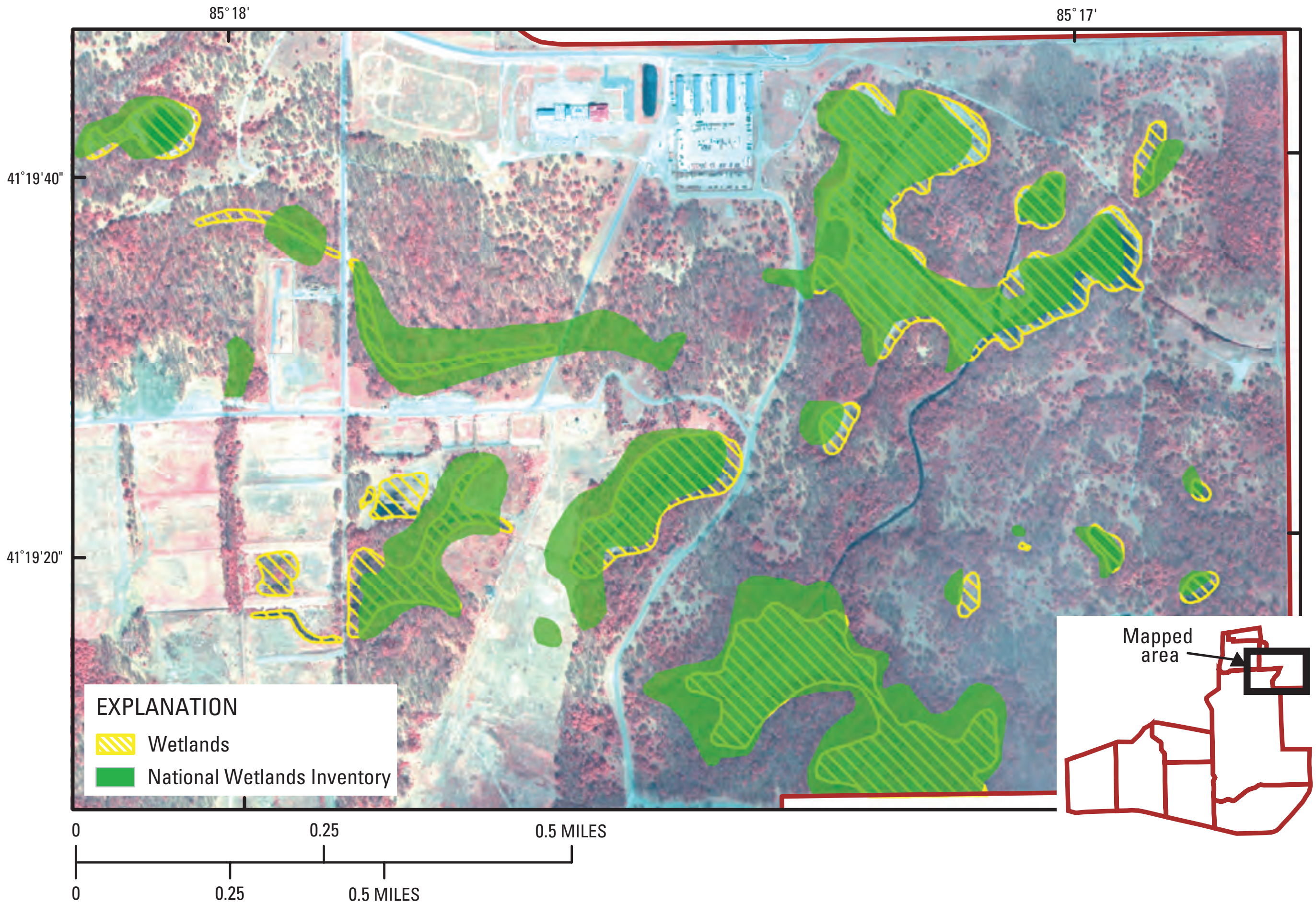


Figure 3. View of the northeast part of Fort Custer Training Center in which the National Wetlands Inventory data are compared to the new digitized wetland map from the IKONOS April 25, 2005, satellite image. The figure shows newly found wetlands that were not included on the National Wetlands Inventory map, an area mapped as wetland in the National Wetlands Inventory data that was determined not to be a wetland according to the IKONOS image and field verification, and adjustments on the boundaries between the two datasets as corrected from the IKONOS image.

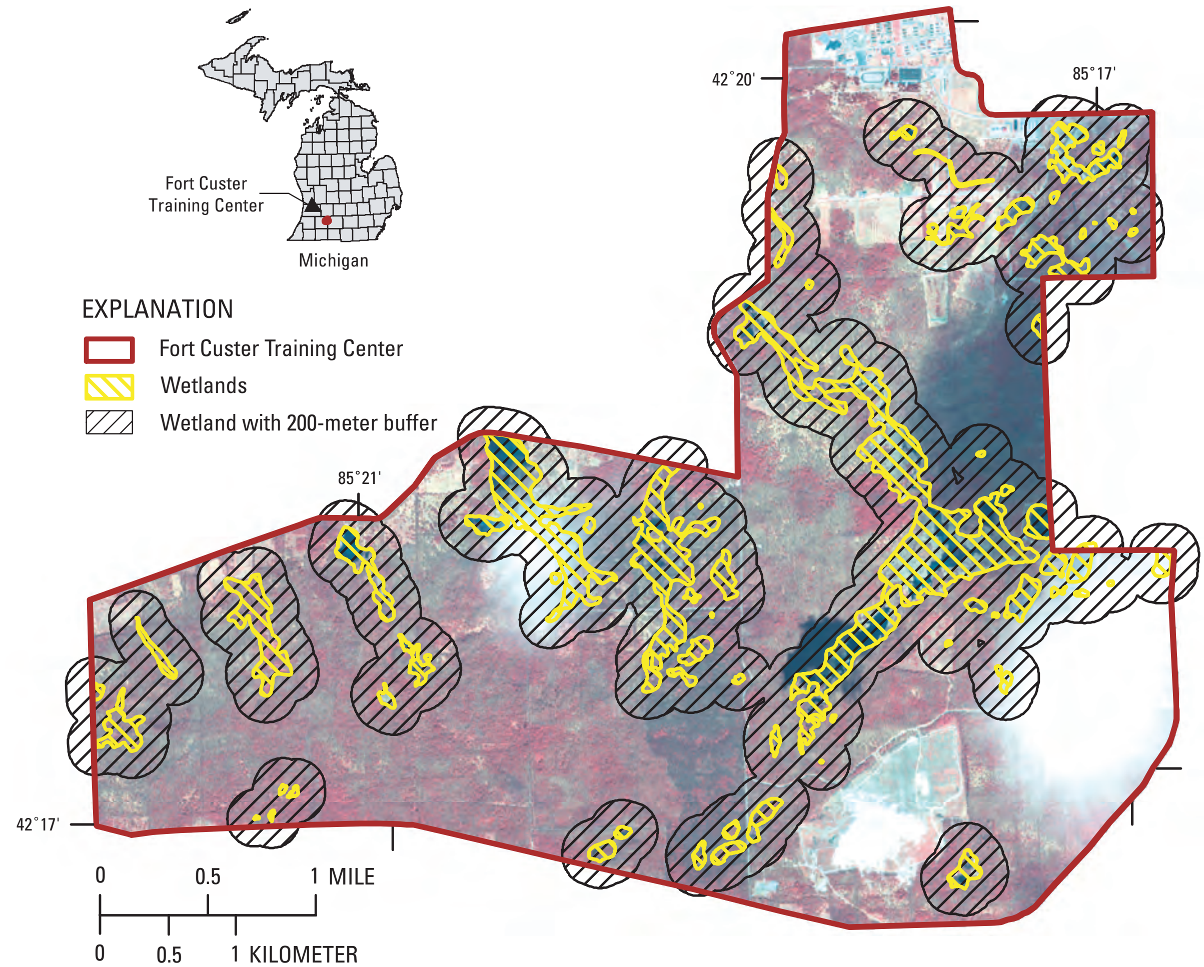


Figure 4. Wetlands mapped from IKONOS satellite imagery April 25, 2005, surrounded by a 200-meter buffer, Fort Custer Training Center, Battle Creek, Michigan

forested wetlands, which were often confused with cloud-shadowed areas and upland areas. When the cloud shadows were removed from the imagery, there was still too much confusion to rely on the automated classifications alone for accurate wetland boundary identification.

In general, the high-resolution IKONOS image did not seem to classify well using automated classifications alone, possibly because the 16-bit image with a pixel size of 0.77 m was too much information to process readily. Within each wetland class there seemed to be a large variation of pixel values; therefore, it was difficult using the automated techniques to group pixels into like patterns that could be identified as wetlands.

The NWI map was visually compared to the satellite imagery and was found to represent FCTC wetlands fairly well. Some wetland areas had a slightly different shape and size on the satellite imagery than on the NWI maps, and some small wetland areas found through the classifications or visual inspections were not identified on the NWI maps.

The final wetland boundary map for the FCTC was manually digitized using the NWI map and the classification technique results as wetland location references. The final size and boundaries of the wetlands were visually determined from the IKONOS imagery or based on GPS field verification. Manual digitizing was possible because the study area was relatively small (7,570 acres).

IKONOS imagery was useful in identifying, verifying, and updating wetland areas for FCTC. The automated classifications and the NWI provided information to identify wetland areas that could be manually digitized for FCTC, although some additional wetland areas were visually identified from the imagery alone. In conclusion, IKONOS imagery is useful in identifying wetlands in relatively small study areas like FCTC (7,570 acres), but more research would be needed to fully automate the process of wetland boundary identification from IKONOS imagery for large study areas where manual digitizing would be too labor intensive and cost prohibitive.

Acknowledgments

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