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CLASSIFICATION ACCURACY ANALYSIS OF SELECTED
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PORTION OF WEST-CENTRAL LOWER MICHIGAN

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CLASSIFICATION ACCURACY ANALYSIS OF SELECTED LAND USE AND LAND COVER PRODUCTS IN A PORTION OF WEST-CENTRAL LOWER MICHIGAN

By

Kin Man Ma

A DISSERTATION

Submitted to
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ABSTRACT

CLASSIFICATION ACCURACY ANALYSIS OF
SELECTED LAND USE AND LAND COVER PRODUCTS
IN A PORTION OF WEST-CENTRAL LOWER MICHIGAN

By

Kin Man Ma

Remote sensing satellites have been utilized to characterize and map land cover and its changes since the 1970s. However, uncertainties exist in almost all land use and land cover maps classified from remotely sensed images. In particular, it has been recognized that the spatial mis-registration of land cover maps can affect the true estimates of land use/land cover (LULC) changes. This dissertation addressed the following questions: what are the spatial patterns, magnitudes, and cover-dependencies of classification uncertainty associated with West-Central Lower Michigan's LULC products and how can the adverse effects of spatial misregistration on accuracy assessment be reduced? Two Michigan LULC products were chosen for comparison: 1998 Muskegon River Watershed (MRW) Michigan Resource Information Systems LULC map and a 2001 Integrated Forest Monitoring and Assessment Prescription Project (IFMAP). The 1m resolution 1998 MRW LULC map was derived from U.S. Geological Survey Digital Orthophoto Quarter Quadrangle (USGS DOQQs) color infrared imagery and was used as the reference map, since it has a thematic accuracy of 95%. The IFMAP LULC map was co-registered to a series of selected 1998 USGS DOQQs. The total combined root mean square error (rmse) distance of the georectified 2001 IFMAP was ±12.20m. A spatial uncertainty buffer of at least 1.5 times the rmse was set at 20m so that polygon core areas would be unaffected by spatial misregistration noise. A

new spatial misregistration buffer protocol (SPATIALM_BUFFER) was developed to limit the effect of spatial misregistration on classification accuracy assessment. Spatial uncertainty buffer zones of 20m were generated around LULC polygons of both datasets.

Eight-hundred seventeen (817) stratified random accuracy assessment points (AAPs) were generated across the 1998 MRW map. Classification accuracy and kappa statistics were generated for both the 817 AAPs and 604 AAPs comparisons. For the 817 AAPs comparison, the overall classification accuracy was 68.79% (kappa=0.627). When the 817 AAPs were overlaid onto the 2001 IFMAP, 213 AAPs within the 20m spatial uncertainty buffer zone were removed. The remaining 604 AAPs were used to assess the map accuracy and results showed that overall classification accuracy was 78.64% (kappa=0.742). The residual, spatial registration noise caused an overall thematic accuracy underestimation of nearly 10%. Therefore, this SPATIALM_BUFFER method was effective in reducing the effects of spatial misregistration on the accuracy assessment of LULC maps.

However, even after removing misregistration noise from consideration, 102 out of 604 AAPs were still misclassified (16.9%). The following land cover classes had the largest number of misclassified AAPs: grassland (12), urban/built up (10), coniferous forest (10), non-forested wetlands (10), and agriculture (9). Therefore, thematic misclassifications were still land-cover dependent and can be influenced by classification system, radiometric, temporal and phenological issues.

Dedicated to my wife, Hyunsook Lee Ma,
and my children, Lindsay ShiShi and Joshua Inwoo

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The Lord God sustains and strengthens. May this research further the knowledge of the natural world around us and help us to value and sustain it for His purposes of preserving our land of Michigan and beyond. This dissertation has been a challenging feat. May this quote express my reverence for the Lord, God Almighty and his help in making this work possible.

"Unless the LORD builds the house, its builders labor in vain. Unless the LORD watches over the city, the watchmen stand guard in vain. In vain you rise early and stay up late, toiling for food to eat—for he grants sleep to those he loves." (Psalm 127: 1-2, NIV)

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KEY TO ABBREVIATIONS

1998 MRW – 1998/1999 Muskegon River Watershed

AAPs – Accuracy Assessment Points

IFMAP – Integrated Forest Monitoring and Assessment and Prescription Project

Landsat ETM+ – Landsat Enhanced Thematic Mapper +

Landsat TM – Landsat Thematic Mapper

LULC – Land Use/Land Cover

MIRIS – Michigan Resource Information Systems

MRW – Muskegon River Watershed

RS & GIS –Remote Sensing and Geographic Information Science Research and Outreach Services

USGS DOQQs – United States Geological Survey Digital Orthophoto Quarter Quadrangles

CHAPTER I

INTRODUCTION

1.1. Remote Sensing of Land Use and Land Cover

Humans have been the major agents of global land use and land cover change since the middle of the 19th century (Houghton and Woodwell, 1989). Humans in the latter part of the 20th century have been dramatically transforming the earth. For example, forested areas have been clearcut for planting crops and agricultural lands have been cleared to build housing developments. This change is widespread though the magnitude of changes is challenging to quantify.

Satellite remote sensing provide the "ability to view the land use and land cover patterns and conditions in a regional context, [which can] lead to understanding the spatial relationships between different uses of the land" (Loveland and DeFries, 2004). The United States' Landsat satellite system of sensors was launched in 1972 and many researchers have utilized archived decadal images from the 1970s, 1980s and 1990s called the North American Landscape Characterization (NALC) data series in order to research land cover change over a thirty year period (Castelli et al., 1998; Nelson et al., 2002). Landsat 7 Enhanced Thematic Mapper (ETM+) images since 1999 have often been used to map land cover and aid in environmental management (Aplin, 2004).

1.2. Michigan's Land Use and Land Cover

Land Use/Land Cover (LULC) classification can be used to characterize land cover at one point in time and a series of temporal LULC maps would show the LULC changes in a dynamic region. The Lower Peninsula of Michigan has a tremendous diversity of land cover types, ranging from urban/built up land to upland forests to agricultural regions to forested wetlands.

There was an historical effort in the mid-1970s to map all of Michigan's land use/land cover. This culminated in a 1978 statewide Land Use/Land Cover map (State of Michigan, 2004). Recently, several Michigan counties such as Wexford, Montcalm and Mecosta counties have updated their 1978 LULC maps to 1998 by mapping out the changes in LULC (Wexford County Extension Office, 2000; Montcalm County Extension Office, 2000; Mecosta County Extension Office, 2000).

In addition, within the Muskegon River Watershed (MRW) in the west-central region of Lower Michigan, a comprehensive LULC update has been completed as part of an environmental monitoring project for this watershed (Annis Water Resources Institute, 2004). This 1998 MRW LULC map spans diagonally across 7,057km^2 of the west-central Lower Michigan has a published thematic accuracy of 95% based on a field verification of 5% of all polygons within each township (RS & GIS, 2004).

Recently, the Michigan Department of Natural Resources (Michigan DNR) completed a statewide land use/land cover map of Michigan called the Integrated Forest Monitoring and Assessment and Prescription Project (IFMAP) (Michigan DNR, 2004). This LULC map was for the 2000/2001 period. Numerous agencies including the Michigan DNR rely on this dataset for current land use/cover information, though the thematic accuracy of this map product has not been independently verified.

1.3. Classification Accuracy and Error

When one classifies land cover, classification accuracy is a continual concern because of issues of spatial accuracy, and spectral and phenological differences between comparison images. When comparing LULC map products, there is much uncertainty regarding the various reasons for misclassifications. Congalton et al. (1983) utilized multivariate statistics to assess the classification accuracy of maps derived from Landsat images. He has set a standard by which remotely sensed classification and accuracy assessment should be used and has developed a solid research method design for limiting classification error and increasing the accuracy of classified phenomena (Congalton, 1991; Congalton and Green, 1999).

The spatial accuracy of vector and raster datasets is also important in LULC map accuracy assessment. More than four decades ago, Perkal (1966) suggested that an 'epsilon' distance should be defined around a cartographic [polygon] line as a means of generalizing it objectively. Because of this concept of the 'epsilon' zone, understanding the spatial accuracy or uncertainty of a boundary and how it can affect the accuracy assessment of LULC maps is important.

More recently, Stow (1999) stated that "[a]ccurate spatial registration is the most critical image processing requirement for reliable assessment of land cover changes that occur at spatial scales that are close to the characteristic dimensions of the ground resolution element of the imagery used to assess the changes (i.e., 'pixel-level' change)." In addition, land cover "change may be overestimated due to positional errors in multi-temporal images, even with sub-pixel co-registration [root mean square] rms errors" (Verbyla and Boles, 2000).

1.4. Research Questions

Various land use/land cover maps have been generated in recent years to quantify the LULC and their changes within Michigan's landscape, although to what extent are these LULC classification map products accurate and represent the true nature of Michigan's LULC and its changes remain unclear.

The following two research questions were addressed by this study:

1) What are the spatial patterns, magnitudes, and cover-dependencies of classification uncertainty associated with west-central Lower Michigan's land use and land cover products in the past decade?

2) What methods can be developed to minimize the adverse effects of spatial misregistration on accuracy assessment of these LULC products?

The goals of this study were to understand whether specific land cover types were more prone to classification uncertainty and also to what extent spatial misregistration of LULC maps influences the nature of the uncertainty and how this uncertainty may be dependent on particular land cover classes.

1.5. Significance of the Study

Researchers such as Verbyla and Boles (2000) estimated the extent to which positional errors affect land cover change estimates and Salas et al. (2003) demonstrated through a Perimeter/ Area ratio, that sliver polygons are the result of spatial misregisration differences between LULC maps. More recently, Wang & Ellis (2005) computed false changes by shifting high resolution ecological maps a series of intervals ranging from 5 m to 400 m and quantifying the effects of positional error on change detection.

However, no research has taken Michigan LULC products and attempted to develop a method to reduce the adverse effects of spatial misregistration on classification accuracy assessment. Also, no methods have been proposed or tested that minimize the adverse effects of spatial misregistration on accuracy assessment in Michigan LULC products. This study will fill in that gap by providing a simple solution to minimize the effects of spatial mis-registration on the accuracy assessment of LULC maps.

CHAPTER II
LITERATURE REVIEW

2.1. Remote Sensing of Land Cover

Satellite remote sensing can observe and monitor large regions of the earth because of the continual orbiting of various satellite systems, such as SPOT (*Satellite Pour l'Observation de la Terre*), Moderate Resolution Imaging Spectroradiometer (MODIS) aboard Terra, and Landsat. These satellites provides the "ability to view the land use and land cover patterns and conditions in a regional context, [which can] lead to understanding the spatial relationships between different uses of the land" (Loveland and DeFries, 2004). Through the use of sensors that are sensitive to specific wavelength bands of the electromagnetic spectrum, they also have the ability to detect reflected infrared energy which aids in the study of vegetation condition, and short-wave energy which aids in the understanding of vegetation moisture differences.

For example, one specific satellite system, the United States' Landsat system of sensors was first launched in 1972. Now, many researchers have utilized the archived decadal images from the 1970s, 1980s and 1990s called the North American Landscape Characterization (NALC) data series to analyze land cover change over a thirty year period (Castelli et al., 1998; Nelson et al., 2002). During a similar period, since the 1980s, remote sensing has helped with land cover classification and provided land cover inventories for improving land management practices. Land cover information has also increased environmental understanding of the earth by investigating the function of land cover in environmental processes (Aplin, 2004). Since 1999, land cover classification has utilized the latest medium scale Landsat 7 Enhanced Thematic Mapper (ETM+) images with a 30 meters pixel resolution.

2.2. Classification Methods and Analysis

For land cover classification, numerous algorithms have been developed to attempt to decipher patterns in the landscape. Jensen (2005) reviewed the main classification methods such as the supervised classification method. The supervised classification method is advantageous when the researcher is familiar with the research area. The researcher selects a representative group of pixels (training pixels) that are identifiable as a specific land cover type, and then choose a group of pixels that represents each of the assigned land cover types. The classification algorithm will then utilize the reflectance signatures of the training pixels and then searches the entire remotely sensed image to identify and find other pixels that match those of the land cover training pixels (Jensen, 2005). On the other hand, the unsupervised ISODATA (Iterative Self-Organizing Data Analysis Technique) classification algorithm is advantageous for the researcher who is not familiar with the landscape of the remotely sensed image. This algorithm requires little human input. An ISODATA algorithm classifies pixels and recalculates cluster mean vectors and assigns them to the desired number of clusters. These clusters are then assigned to the specific LULC type within a specific LULC classification scheme (Jensen, 2005).

A series of classification methods and algorithms have been developed to improve classification accuracy. Bruzzone and Cossu (2002) had combined both "multiple classification algorithms and multitemporal imagery in a new cascading classification structure to enable the regular updating of land cover maps" (Aplin, 2004).

For another classification algorithm, Sohn et al.'s (1999) cosine of the angle concept (CTAC) classifier showed the power of this method to classify different shapes in the landscape. When classifying the secondary succession forest and agricultural land types of the north-central Yucatan, the CTAC method utilized the spectral angle of the different successional forest lands to differentiate the slight variations between the forest and agricultural land cover types. In a subsequent study, this CTAC method was then evaluated against other unsupervised and supervised land cover classifiers. Sohn & Rebello's (2002) research results demonstrated that the CTAC was very effective in delineating the spectral shape patterns of different land-cover/land-use types.

The above classification algorithms assume a binary type of land cover classification. However, in a diverse landscape, the boundary between the two land cover class types, such as the edge between cornfields and forested land, is difficult to classify accurately. Classification depends on the spatial resolution, and the image pixel that has spectral reflectance from the corn and forest land cover types would produce a "mixed" pixel of reflectance. It is neither 100% corn, nor 100% forest. Therefore, there has been a trend in classification to expand beyond an either/or dichotomy of land cover classes, but to utilize a "fuzzy classification" in which the land cover can be classified a specific percentage of a particular land cover class, such as 30% corn (Foody, 1999).

Moreover, when evaluating several classification algorithms, the costs of accuracy assessment play a large role in the type of algorithm utilized and the investment in field checking of reference data points was important. They proposed a protocol for "assessing the quality of classification results, related to the economical aspects of a specific remote-sensing project" (Smits et al., 1999). When classification algorithms are evaluated and compared, the kappa coefficient, $\hat{k}$ statistic, is the most common and effective statistic utilized to compare classification accuracy as show in the equaltion below (Lillesand and Kiefer, 2000; Congalton and Green, 1999; Smits et al., 1999).

$$\hat{k} = \frac{observed\_accuracy - chance\_agreement}{1 - chance\_agreement}$$

2.3. Classification Accuracy and Uncertainty

When one classifies land cover, classification accuracy is a continual concern because of issues of spatial accuracy, and spectral and phenological differences between comparison images. A representative number of ground truth points are needed within the various land cover types in order to produce an accurate classification map from remotely sensed data. Congalton et al. (1983) utilized multivariate statistics in order to evaluate classification accuracy of Landsat imagery. Congalton (1991) set the standard by which remotely sensed classification and accuracy assessment should be undertaken and has developed a solid research method designed for limiting classification error and increasing the accuracy of classified phenomena (Congalton, 1991; Congalton and Green, 1999).

Classification accuracy has often been adversely affected by the problem of "mixed" pixels that are on the edges of two different land cover types. This problem of the "mixed" pixel will not be easily resolved, though by understanding how this problem is linked to pixel size and resolution, will help the interpretation of classification results.

In addition, Foody (2002a) systematically reviewed the current status of classification accuracy assessment. He cautioned that hard binary classification systems "would be expected to underestimate the area of land undergoing a change and, where a change is detected, overestimate the magnitude of change as it is a simple binary technique" (Foody, 2002a). The traditional approach to accuracy assessment involves three primary components, the sample design that determines which subregions or points will be sampled, the response or measurement design to obtain the true or "reference" attribute for each sampled unit or point, and the analysis of the data obtained (Stehman and Czaplewski, 2003).

2.3.1. Spatial Accuracy Assessment Protocol

When evaluating map accuracy, Biging et al. (1998) reviewed various sampling method protocols for effective accuracy assessment. They concluded that a stratified random sampling protocol should be used to increase the precision over a simple random sampling protocol technique (Biging et al., 1998). Nusser and Klaas (2003) demonstrated the method of allocating a set of stratified random "reference" points across their Iowan research fields. They randomly chose ground truth points from their 29 land cover type categories, though in their accuracy analysis they took the "important step of calculating standard errors for the [accuracy] estimates" (Stehman and Czaplewski, 2003).

Patil and Taillie (2003) studied the differences between two classified maps having the same spatial extent. Overlaying the maps yielded a dissimilarity matrix. They developed a "parametric model, called latent truth model, by specifying the dissimilarity matrix in terms of the true proportions for the mapping categories as well as the unknown error rates for the two maps" (Patil and Taillie, 2003). They then generated accuracy assessment characteristics for the two maps from Wicomico County, Maryland.

However, Stehman (2001) had demonstrated that there needs to be a balance of statistical rigor and practical utility in thematic map accuracy assessment, the reporting of standard errors is necessary to evaluate precision and the sampling protocols of assessment points must be clearly documented. Practical utility was framed in terms of tradeoffs between cost versus quality in which four quality criteria must be evaluated while considering the 'resources' available to the researcher: "precision, population representation, assumptions, and accuracy of the reference data" (Stehman, 2001).

When comparing LULC map products, there is much uncertainty regarding the various reasons for misclassifications. Foody and Atkinson (2002) stated that, "we are a long way from having an 'uncertainty button' in our geographic information systems [software]. Indeed, we are a long way from appreciating fully uncertainty and its impacts... [There are also] "fundamental spatial relations, such as nearness" that have not been fully explored (Foody and Atkinson, 2002).

2.3.2. Spatial Accuracy and Resolution

Accuracy assessment can also be influenced by pixel resolution. The spatial scale or pixel resolution can make a significant impact on the phenomena being observed. Openshaw (1984) first discussed the modifiable areal unit problem (MAUP) and showed that if the patch size of the phenomenon is small, the pixel resolution needs to match this size in order to be effective in measuring it. Cao and Lam (1997) stated that "the scale problem arises because of the uncertainty about the number of zones most appropriate for a particular study, and the aggregation problem arises because of the uncertainty about how the data are to be aggregated to form a given number of zones" (Cao and Lam, 1997).

In addition to spatial resolution, the spatial accuracy of vector and raster datasets are also important in LULC map accuracy assessment. Perkal (1966) suggested that an 'epsilon' distance should be defined around a cartographic [polygon] line as a means of generalizing it objectively. Because of this concept of the 'epsilon' zone, understanding the spatial accuracy or uncertainty of a boundary and how it can affect the accuracy assessment of LULC maps is important.

More recently, Stow (1999) stated that "[a]ccurate spatial registration is the most critical image processing requirement for reliable assessment of land cover changes that occur at spatial scales that are close to the characteristic dimensions of the ground resolution element of the imagery used to assess the changes (i.e., 'pixel-level' change)." More specifically, Dai and Khorram (1997) showed "that highly accurate change detection based on multi-temporal Landsat Thematic Mapper images requires that the magnitude of mis-registration be less than 0.2 pixel."

Verbyla and Boles (2000) found that land cover "change may be overestimated due to positional error in multitemporal images, even with sub-pixel co-registration rms errors" (Verbyla and Boles, 2000). Moreover, Salas et al. (2003) tried to improve land cover change estimates by employing a perimeter/area ratio as an index of misregistration bias. They found that "almost 10% of the total change from cropland to vegetated areas [in Guangdong, China] could be due to single pixel misregistration" (Salas et al., 2003).

Wang and Ellis (2005) computed false changes by shifting high resolution ecological maps a series of intervals ranging from 5 m to 400 m and quantifying the effects of positional error on change detection. Bruzzone and Cossu (2003) proposed an adaptive approach aimed at reducing the effects of registration noise in unsupervised change detection. They developed an adaptive and nonparametric estimation of the distribution of registration noise in a magnitude-direction space through a complex, mathematical formulation involving the change vector analysis (CVA) technique (Bruzzone and Cossu, 2003).

None of these studies proposed an effective method of reducing the effects of misregistration noise on thematic accuracy assessment.

2.4. Michigan LULC Products

There was an historical effort in the mid-1970s to map all of Michigan's land use/land cover. This culminated in a 1978 statewide Land Use/Land Cover map (State of Michigan, 2004). Recently, several Michigan counties such as Wexford, Montcalm and Mecosta counties have updated their 1978 LULC maps to 1998 by mapping out the changes in LULC (Wexford County Extension

Office, 2000; Montcalm County Extension Office, 2000; Mecosta County Extension Office, 2000).

In addition, within the Muskegon River Watershed (MRW) in the west-central region of Lower Michigan, a comprehensive LULC update has been completed as part of an environmental monitoring project for this watershed. This 1998 MRW LULC map has a published thematic accuracy of 95% based on a field verification of 5% of all polygons within each township (RS & GIS, 2004).

Recently, the Michigan Department of Natural Resources completed a statewide land use/land cover map of Michigan called the Integrated Forest Monitoring and Assessment and Prescription Project (IFMAP) (Michigan DNR, 2004). This LULC map was for the 2000/2001 period. The thematic accuracy of this map product has not been independently verified.

After reviewing the literature, it became clear that a comprehensive study of the spatial patterns, magnitudes, and cover-dependencies of classification uncertainty was lacking. The literature review also revealed that all LULC map products exhibit some degree of spatial inaccuracy and this spatial mis-registration noise confounds traditional accuracy assessment procedures.

CHAPTER III

RESEARCH DESIGN AND METHODOLOGY

3.1. Study Area

The Muskegon River Watershed extends diagonally across the west-central portion of Lower Michigan encompassing parts of eleven counties. There is a tremendous diversity of land use/land cover types within the 7,057 km^2 of the watershed, ranging from urban to upland forests to agricultural regions (Figure 3.1). This area was chosen because the LULC of this diverse landscape was mapped by high spatial resolution imagery and its 95% thematic accuracy makes it a good candidate for a reference map to assess the accuracy of the 2001 Integrated Forest Monitoring and Assessment Project (IFMAP) LULC product referenced below in section 3.2.2.

3.2. Data Sources

For Michigan's Lower Peninsula, several LULC map products have been produced over the last decade. Two of the available LULC map products were chosen, 1) the 1998 Muskegon River Watershed LULC map, and 2) the 2001 IFMAP LULC map (see Table 3.1). These maps and corresponding legends show land use/land cover types and are displayed in a variety of colors. Many images in this dissertation are presented in COLOR to differentiate the LULC types.

Table 3.1: Image Data Sources

Data Source	Image Source	Date of Imagery	Spatial Resolution
selected USGS DOQQs	CIR Orthophotography	April 1998	1 m
1998/1999 MRW	CIR Orthophotography	April 1998, April 1999	1 m
2001 IFMAP	Landsat TM and ETM+	Multiple Dates (see below)	30 m
	Path22, Row30	25-Mar-2000 Leaf Off (ETM+)	
	Path22, Row30	13-Jul-1999 MidSeason (ETM+)	
	Path22, Row30	11-Oct-00,19-Oct-00 (TM, ETM+)	
	Path22, Row29	26-Apr-2000 Leaf Off (ETM+)	
	Path22, Row29	2-Jul-2001 MidSeason (ETM+)	
	Path22, Row29	19-Oct-00 (ETM+)	
	Path21, Row 29	8-Mar-2001 Leaf Off (ETM+)	
	Path21, Row 29	25-Jun-2001 MidSeason (ETM+)	
	Path21, Row 29	29-Sep-2001 (ETM+)	

3.2.1. 1998 Muskegon River Watershed LULC Map

The 1998 MRW LULC map was derived from 1 meter pixel resolution color infrared aerial imagery acquired in April 1998 and April 1999 by the National Aerial Photography Program (NAPP), and also known as the U.S. Geological Survey's Digital Orthophoto Quarter Quadrangle images (RS & GIS, 2004). This LULC classification was performed by the Remote Sensing and Geographic Information Science Research and Outreach Services (RS & GIS), Michigan State University for the Annis Water Resources Institute (AWRI), Grand Valley State University. The interpretation of land use/land cover classes to Level III of the Michigan LULC classification system was performed by two separate interpreters (RS & GIS, 2002). "The [1998 MRW] polygons were at a scale of 1:24,000 and equates to a spatial accuracy of ±12.19 meters and there was a 95% overall classification accuracy" (RS & GIS, 2004). Also, "5% of polygons within each township were field verified, especially unknown polygons, ambiguous polygons and random polygons" (RS & GIS, 2004). Field verification was performed by the staff of the RS & GIS, and the AWRI. This vector polygon dataset was in a Michigan Georef projection (Figure 3.1). In addition, the "minimum mapping unit (MMU) was 2.5 acres or 1 ha and the minimum mapping distance (MMD) was 100 feet (30.48 meters)" (RS & GIS, 2004).

This LULC dataset is the most comprehensive, high-resolution LULC dataset available for west-central Lower Michigan. Because this "wall to wall" LULC dataset encompassed more than 7,000 km^2 of diverse landscape and was systematically field checked, it can be considered a ground "truth" map for verifying and evaluating coarser resolution datasets of the same area. Congalton and Green (1999) noted that photo interpreted images can be used in place of true ground reference data points, if a subset of the land area has also been field verified. The 1998 MRW LULC map meets this criterion and was used to evaluate the accuracy of the 2001 IFMAP LULC product.

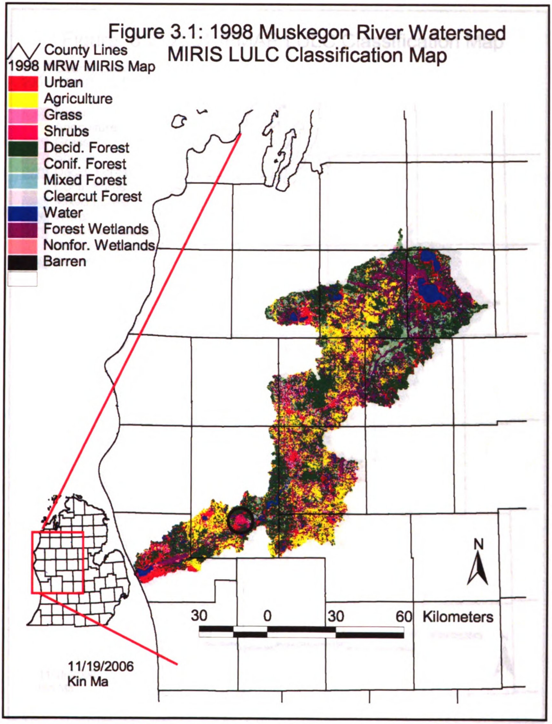
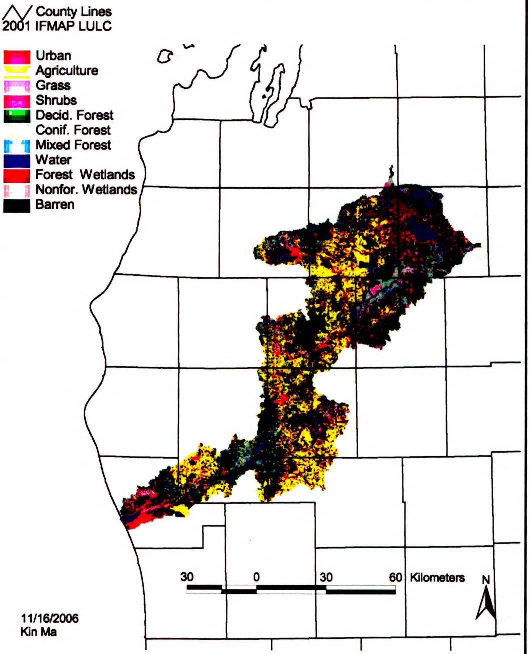


Figure 3.1: 1998 Muskegon River Watershed
MIRIS LULC Classification Map
County Lines
1998 MRW MIRIS Map
Urban
Agriculture
Grass
Shrubs
Decid. Forest
Conif. Forest
Mixed Forest
Clearcut Forest
Water
Forest Wetlands
Nonfor. Wetlands
Barren
N
30
0
30
60
Kilometers
11/19/2006
Kin Ma

Figure 3.2: 2001 IFMAP LULC Classification Map



3.2.2. 2001 IFMAP LULC Map

The Integrated Forest Monitoring and Assessment Project (IFMAP) 2001 LULC dataset was acquired through the Michigan Department of Natural Resources (Michigan DNR), Resource Mapping and Aerial Photography Section and provided in Geotiff format, with a 30m cell size in a Michigan Georef projection. This LULC map was derived from a series of Landsat TM and ETM+ images for both the early spring, mid-summer, and early fall periods (Table 3.1). This classification emphasized forest inventory and classification and, according to the 2004 IFMAP report, had a classification accuracy of 87.7% at Level II utilizing the 2003 Forest Inventory and Assessment (USFS, FIA) data points for classification verification (Michigan DNR, 2004). The 2001 IFMAP LULC map of the entire state of Michigan was completed in 2004. Numerous agencies including the Michigan DNR rely on this dataset for current land use/cover information, but there has not been an independent verification of its classification accuracy.

The IFMAP classification was generated in the following manner and the entire classification procedure paragraph is quoted from the 2004 IFMAP report:

The IFMAP "primary classifier was a cluster analysis method developed by Chuveico and Congalton (1988), which matched clusters from an unsupervised classification with the training site data collected by the field crews. In this process, several outcomes for a given cluster were possible. The cluster analysis method was an iterative process, whereby clusters were labeled with a land cover class based on their spectral distance from a given set of training statistics. In the first iteration, the summer image mosaic was classified using the ISODATA unsupervised method. The resulting classes were grouped with the supervised classes using an agglomerative hierarchical procedure (Mathsoft, 2000). This procedure began by considering each signature as a separate group, then it combined and divided groups based on spectral similarity until all signatures were in a single group, displayed in a hierarchical structure according to the order in which the groups were merged or divided. The resulting clustering tree was then examined for matches of supervised and unsupervised signatures, and in the case of a close one-to-one relationship, the unsupervised signature in question was labeled with the land cover label of the supervised signature. After the tree was fully examined for clusters of this type, the labeled classes were subset from the imagery, and the procedure was run again. This procedure continued until it was no longer advantageous to do so. The cluster analysis method was used initially on the entire image to achieve an Anderson Level 1 classification, and subsequently on a subset of the image for each individual Level 1 cover type" (MDNR, 2004, p. 19).

3.2.3. U.S. Geological Survey Digital Orthophoto Quarter Quadrangles

Selected U.S. Geological Survey Digital Orthophoto Quarter Quadrangles DOQQs) for Michigan were obtained from the Center for Geographic Information, Geographic Data Library (Michigan CGI, 2006). For the 1998 date series, DOQQs are available for the entire state of Michigan, have a 1 meter pixel size and are in the Michigan GeoRef projection format. Several of these images were chosen to georectify the 2001 IFMAP LULC map. Four DOQQs were selected to cover the four areas within the expanse of the Muskegon River Watershed. For example, the DOQQs named Houghton Lake SE, Cadillac North SE, Twin Lake SE, and Dalton NE, covered the following four regions: 1) the northeast region near Houghton Lake, 2) the western region near Cadillac, MI in Wexford County, 3) the central region of Mecosta County near Rodney, MI and 4) the southwestern region north of the city of Muskegon.

3.3. Research Methods

There has been increasing evidence that spatial misregistration can negatively affect the overall classification accuracy assessment of LULC map comparisons (Stow, 1999; Verbyla and Boles, 2000; Salas et al., 2003). A method was developed to eliminate the adverse effect that spatial misregistration has on classification accuracy assessment. Within the following image processing protocol below, a spatial accuracy and misregistration buffer zone method was developed to prevent accuracy assessment points (AAPs) from being positioned in the zone of uncertainty due to spatial misregistration between the two LULC maps.

3.3.1. LULC Codes, Image Processing and Buffer Zone Method Protocol

3.3.1.1. LULC Code System and Re-Coding Procedure

Since the 1998 Muskegon River Watershed (MRW) LULC map had 1 m resolution and also an overall accuracy of 95%, this map became the reference map for evaluating the classification accuracy of the 2001 IFMAP LULC product. The land use categories of the 1998 MRW LULC map had been classified to Level III of the Michigan system (RS & GIS, 2002). In this dissertation, these LULC classes were re-coded to conform to the generalized Level I/II combined LULC codes shown in Table 3.2. Land Use/Land Cover types from the 2001 IFMAP LULC product were also re-coded to the same modified Michigan Level I/II LULC classification system (Table 3.2).

Table 3.2: Land Use/Land Cover Code and Names

LU Code	LU Class Name	LU Code	LU Class Name
1	Urban	7	Mixed Forest
2	Agriculture	8	Clearcut Forest
3	Grass	9	Water
4	Shrubs	10	Forested Wetlands
5	Deciduous Forest	11	Nonforested Wetlands
6	Coniferous Forest	12	Barren Land

The specific re-code relationships for both the MRW and IFMAP LULC maps are shown in Table 3.3. Note that the category of clearcut forest, MRW class #44 (a classification of forest that has been cleared to below 16.7% stocking density) was not mapped by IFMAP. Because of this discrepancy between the two classification systems, the clearcut forest category was not utilized in any of the LULC comparisons.

Table 3.3: Land Use Class Assignment Comparison

LU	LU Class	2001 IFMAP LU_Names	1998 MRW MIRIS Classes
1	Urban	Low Intensity Urban	Residential Housing
1	Urban	Airports	Commercial
1	Urban	Roads / Paved	Industrial
1	Urban	High Intensity Urban	Transport/Utilities
1	Urban		Extractive
1	Urban	Parks / Golf Courses	Open Land
2	Agriculture	Non-vegetated Farmland	Cropland
2	Agriculture	Row Crops	
2	Agriculture	Forage Crops	
2	Agriculture	Orchards / Vineyards	Orchards
2	Agriculture		Confined Feeding
2	Agriculture		Permanent Pasture
2	Agriculture		Other Agric. Land
3	Grass	Herbaceous Openland	Grasses and Forbs
4	Shrub	Upland Shrub	Shrub Open Field
5	Decid. For.	Northern Hardwoods	Northern Hardwoods (#411)
5	Decid. For.	Oak Association	Central Hardwoods/Oak (#412)
5	Decid. For.	Aspen Association	Aspen/Birch (#413)
5	Decid. For.	Mixed Upland Deciduous	
6	Conif. For.	Pines	Pines (#421)
6	Conif. For.	Other Upland Conifers	Other Upland Conifers (#422)
6	Conif. For.	Mixed Upland Conifers	Christmas Tree Plantation (#429)
7	Mixed For.	Upland Mixed Forest	Mixed Forest (#43)
8	Clearcut Forest	**NOT in classification**	Clearcut Forest (#44)
9	Water	Water	Streams/Waterways
9	Water		Lakes/Ponds
9	Water		Reservoir
10	For. Wetlands	Lowland Decid. Forest	Lowland Decid. Forest (#414)
10	For. Wetlands	Lowland Conif. Forest	Lowland Conif. Forest (#423)
10	For. Wetlands	Lowland Mixed Forest	Forested Wetlands (#61)
10	For. Wetlands	Lowland Shrub	
11	Nonfor. Wetlands	Floating Aquatic	Nonfor. Wetlands (#62)
11	Nonfor. Wetlands	Emergent Wetland	Aquatic Bed (#621)
11	Nonfor. Wetlands	Mixed NonForest Wetland	
12	Barren	Sand / Soil	Beach/Riverbank (#72)
12	Barren	Bare/Sparsely Veg	Sand Dune (#73)
12	Barren	Exposed Rock	Exposed Rock (#74)

LU = Land Use Code
LU Class = Land Use Class Names
2001 IFMAP LU_Names = 2001 IFMAP Land Use Class Names
1998 MRW MIRIS Classes = 1998 MRW MIRIS Land Use Class Names

3.3.1.2. Image Processing of the 1998 MRW LULC map

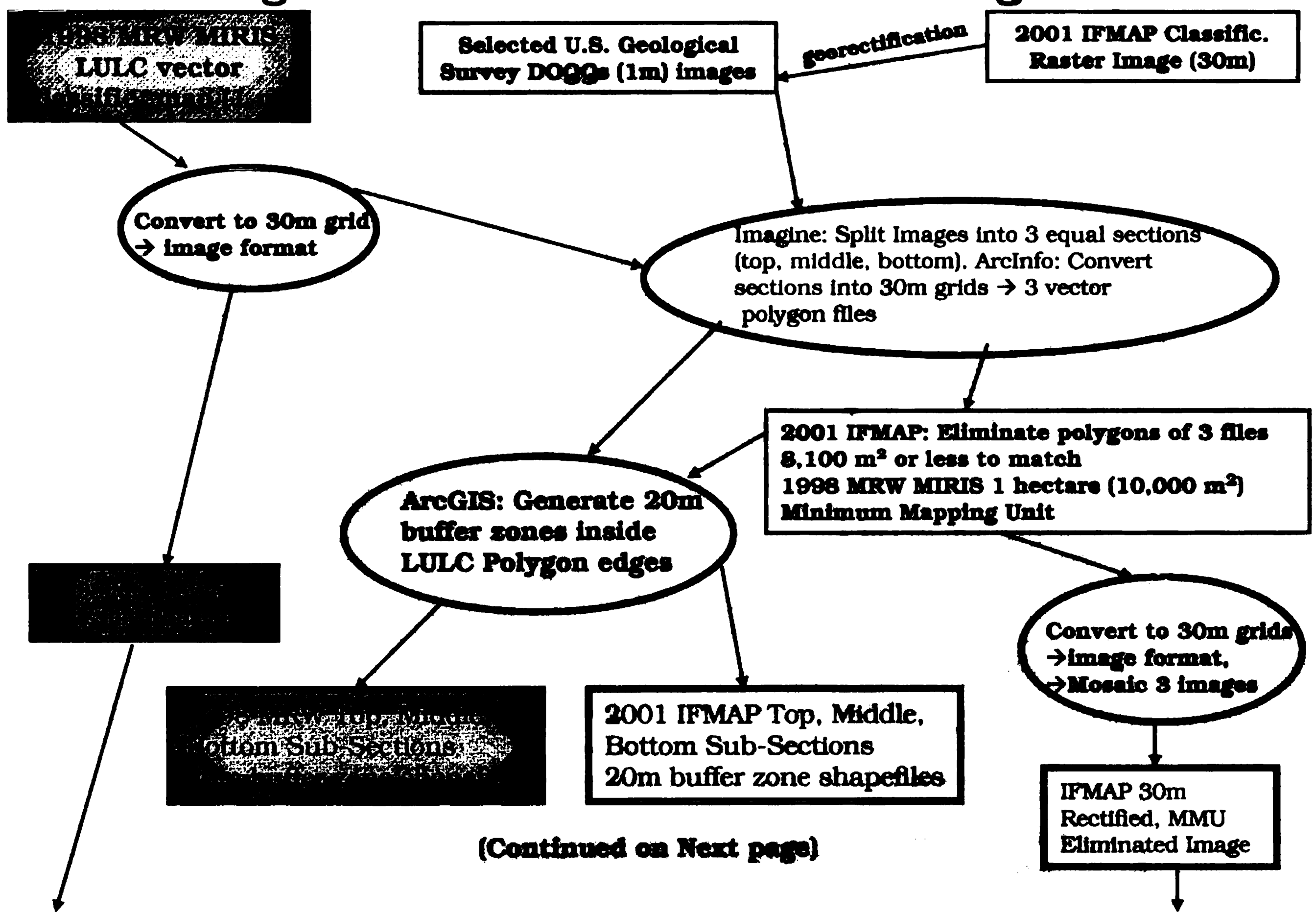
The 1998 MRW LULC file was originally in an ArcView shapefile format. Level I/II land cover codes were assigned as shown in Table 3.3 and an ArcInfo GRID command (shapegrid) converted the shapefile to a 30m cell size raster file to match the spatial resolution of the 2001 IFMAP LULC map (Figure 3.3). It was then converted from a grid file to a 30m pixel size image file for processing in ERDAS Imagine software.

This image (.img file) was subset into three equal parts, 1) top, 2) middle, and 3) bottom, because the ArcGIS vector buffering function had difficulty processing the large number of polygons within the 1998 MRW vector coverage (a geoprocessing necessity due to computational limitations). After subsetting, the three subsection images were each converted back to a grid format and subsequently transformed into three vector polygon coverages (see Figure 3.3).

3.3.1.2a. 1998 MRW Buffer Zone method

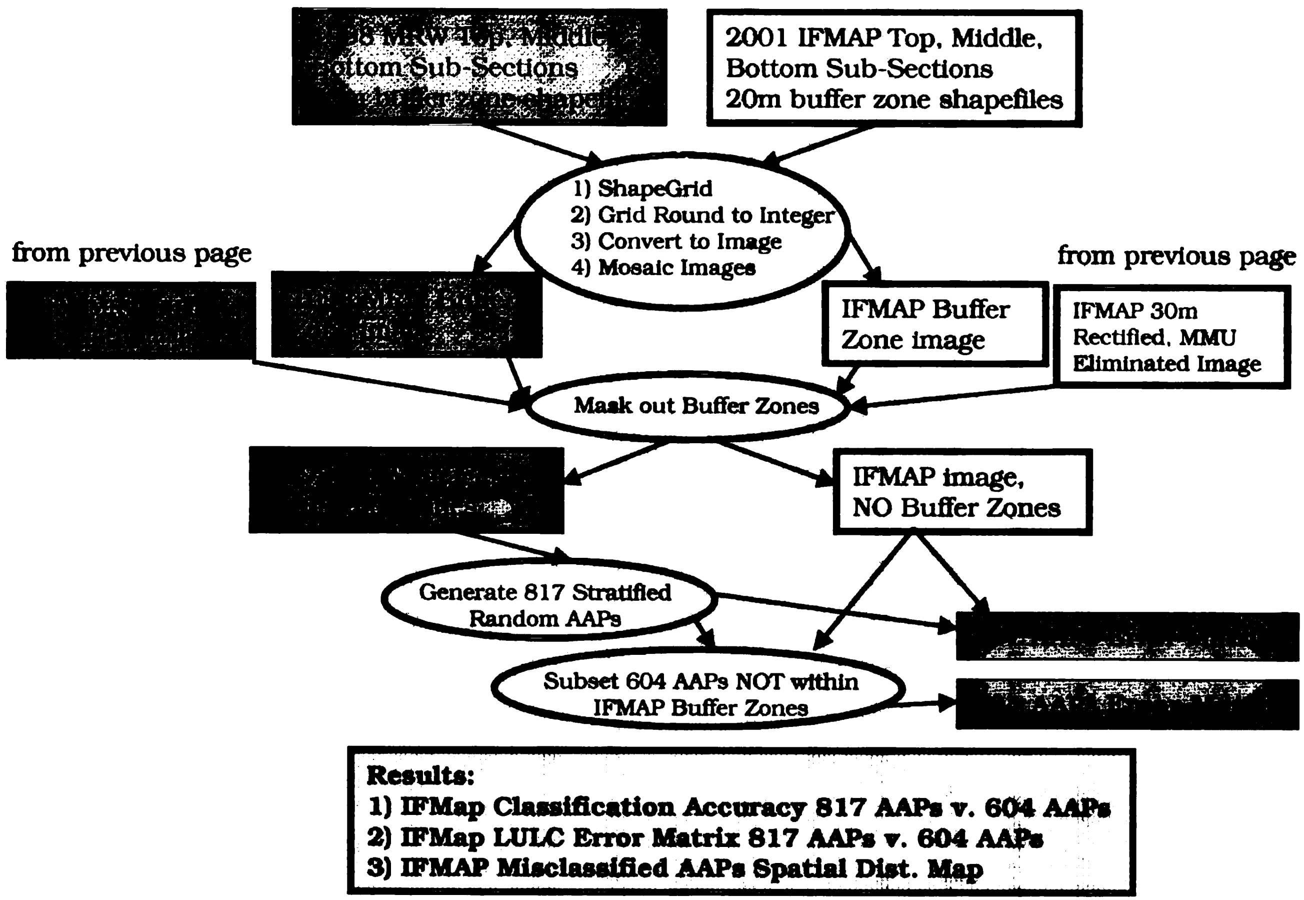
The spatial accuracy of the 1998 MRW dataset, as provided by the image's metadata, was ±12.19m. The spatial accuracy of the IFMAP image (see section 3.3.1.3, below) was calculated as a root mean square error (rmse) distance of ±0.6m relative to the 1998 MRW LULC map. Therefore, the total combined rmse distance was ±12.20m. This distance would be the minimum buffer zone of spatial misregistration between these two datasets. As a further safeguard, the spatial uncertainty zone was increased to 20m, at least 1.5 times the rmse distance, in order to be certain that the AAPs would fall within the polygon core areas that were unaffected by spatial misregistration noise.

Figure 3.3: Research Methods Diagram



(Continued on Next page)

Figure 3.3: Research Methods (Cont'd)



The ArcGIS buffer function was used to calculate a 20m buffer zone inside each LULC polygon. After the buffer function calculated this 20m zone within every LULC polygon, a shapefile of areas labeled '-20' m around each polygon edge boundary was generated and converted to a 30m cell size grid using the ArcInfo 'shapegrid' function. Unfortunately, the '-20'm buffer grid had 'floating point' values that needed to be rounded to integers. This conversion was accomplished using an ArcView extension, named "Grid Round-Floating Point to Integer," that was downloaded from the http://www.esri.com website (Corradini, 2006). Each of the 1998 MRW's three sub-section grids were rounded to a '-20' value integer and then multiplied by '-10' so that the resulting grid would have a positive value of '200'. This conversion was necessary since grids having negative values cannot be imported by the ERDAS Imagine software program. After each of the three '200' value sub-section buffer grids were imported into ERDAS Imagine, the three image files for the top, middle and bottom sections of the MRW, were mosaicked together to form a one seamless image that had 40-meter-wide epsilon zones centered along the boundaries of each LULC polygon (i.e., group of pixels) (Figure 3.3, 2nd page).

The 1998 MRW 'buffer zone' image described above was used to mask out the uncertainty zone within the 1998 MRW LULC map. After these processing steps, a 1998 MRW 'NO buffer zones' image was created and ready for error matrix evaluation with the 2001 IFMAP 'NO buffer zones' image (see Figure 3.3, 2nd page).

3.3.1.3. Image Processing of the 2001 IFMAP LULC map

The 2001 IFMAP LULC map was co-registered to the above referenced USGS DOQQs. Within each of the four selected DOQQs, a Ground Control Point (GCP) was chosen at the corner of a coniferous forest stand that was viewed in the selected DOQQ images, the 1998 MRW and 2001 IFMAP images. The 2001 IFMAP image was rectified to the 1998 MRW image using the four chosen GCPs within the DOQQ images, the rmse distance for the 2001 IFMAP image was ±0.6m. Therefore, the total combined rmse distance for the 2001 IFMAP image relative to the 1998 MRW image was ±12.20 m.

After geometric registration, the 2001 IFMAP was subset into three equal parts, 1) top, 2) middle, and 3) bottom by utilizing the same area of interest (AOI) boundaries that were used to subset the 1998 MRW image. This subsetting was necessary because the ArcGIS vector buffering function had difficulty processing the very, large number of polygons (810,000+) generated by the entire IFMAP image of the MRW. After subsetting, each of the three IFMAP subsection images were converted to grid files and subsequently converted to vector polygon coverages (see Figure 3.3). Even after splitting the IFMAP image into 3 subsections, each of the subsections still had too many polygons to effectively run the ArcGIS buffering function (e.g., the IFMAP bottom subsection coverage had 241,000+ polygons).

Since the original IFMAP LULC map was derived from Landat TM and ETM+ images, the classification generated numerous 30m single-cell polygons. Using ArcInfo, these small polygons were eliminated to match the minimum mapping unit classification of the 1998 MRW LULC map, (1 ha or 10,000 m^2). The equivalent of 3 x 3 30m cell size group of polygons, or 8,100 m^2, were eliminated from each of the three IFMAP section vector coverages. Nearly 90% of the polygons within each of the section coverage files were equal to or smaller than the 8,100 m^2 minimum mapping unit. The LULC labels of the small polygons were re-assigned to the LULC label of the closest, adjacent polygon that was larger than 8,100 m^2, and the boundary lines of the small polygon shapes were dissolved (Figure 3.3). The resulting spatially, filtered coverages had fewer than 27,000 polygons.

3.3.1.3a. IFMAP Buffer Zone method

The rmse distance for the IFMAP image (±12.20m) would be the minimum buffer zone of spatial uncertainty for this dataset. The uncertainty zone due to spatial misregistration was increased to 20m, at least 1.5 times the rmse distance, in order to be certain that the AAPs would fall within the polygon core areas that were unaffected by spatial misregistration noise.

The ArcGIS 9.0 buffer function was used to calculate a 20m buffer zone inside each LULC polygon in the IFMAP product and a shapefile of areas labeled '-20' m around each polygon edge boundary was generated. The '-20'm buffer shapefile was converted to a 30m cell size grid file by an ArcInfo 'shapegrid' function. The buffer zone generation protocol for the three IFMAP section coverages matched that of the 1998 MRW image buffering protocol above and generated an IFMAP buffer zone image that had 40-meter-wide epsilon zones centered along the boundaries of each LULC polygon (i.e., group of pixels) (see Figure 3.3, 2nd page).

Before proceeding to the next step, the IFMAP 'eliminated' polygon coverages that had the minimum mapping unit (MMU) polygons (8,100 m^2)

removed, were converted back to Imagine (.img) files using ArcInfo grid. These three "MMU-eliminated" IFMAP images of the top, middle, and bottom sections of the Muskegon River Watershed were then mosaicked back together to form a seamless 2001 IFMAP 'MMU-eliminated' image.

The IFMAP 'buffer zone' image from above was used to mask out the spatial uncertainty zone within the IFMAP 'MMU-eliminated' image. After these processing steps, the IFMAP "NO buffer zones" image was ready for error matrix evaluation against the 1998 MRW "NO buffer zones" image (see Figure 3.3, page 2). This complete process (Figure 3.3) of generating a buffer zone around LULC polygon edges to limit the adverse effects of spatial misregistration on accuracy assessment, is called the spatial misregistration buffer method protocol or SPATIALM_BUFFER protocol.

3.3.2. Choice of Accuracy Assessment Points

Since the 1998 MRW LULC map had a high overall classification accuracy (95%), the 40-meter-wide epsilon zone buffer-removed version of this dataset was utilized as the base classification for comparison to the 2001 IFMAP LULC map product. Congalton and Green (1999) have suggested that in a heterogenous landscape (like the MRW), effective classification accuracy assessment requires generating a group of stratified random accuracy assessment points (AAPs) within each of the land cover categories. Utilizing ERDAS Imagine Accuracy Assessment module, the following choices under 'Class Value Assignment' options were selected: Window Size = 3; Window = Majority Rule; and Majority Threshold = 9. These choices force the Accuracy Assessment module to generate stratified random AAPs only within the "center of mass" of each LULC category (i.e., the point must fall within a homogeneous 3 x 3 cell or larger window). Stratified random points were generated in order to have at least 25 AAPs for each of the 12 land cover types listed in Table 3.2.

For improved classification accuracy analysis by eliminating the influence of spatial misregistration on the comparison, the uncertainty zones in both maps were avoided when selecting potential AAP locations. Overall, 817 stratified random AAPs were generated utilizing the 1998 MRW "NO buffer zones" map as the "truth" map. These AAPs were well distributed throughout the Muskegon River Watershed region (see Figure 3.4). A classification accuracy and kappa statistic was generated for these 817 AAPs.

However, when these 817 AAPs were overlaid on the 2001 IFMAP classification map, 213 of them (26.1% of the total) landed within the IFMAP spatial uncertainty zones. Including these AAPs would confound the error matrix analysis, since the influence of the spatial misregistration, in addition to thematic misclassification, cannot be discounted in these uncertainty zones. Therefore, these 213 AAPs were eliminated from the total AAP selection, and thus, 604 stratified random AAPs remained, none of which were located within either of the spatial misregistration buffer zones. Classification accuracy and kappa statistics were generated for both the 817 AAPs comparison and the 604 AAPs comparison, in order to demonstrate the efficacy of the spatial misregistration buffer method protocol and its effect on thematic accuracy assessment (Figure 3.5).

3.3.3. LULC Map Comparisons and Error Matrix Evaluation

Producer's and user's accuracies were analyzed to characterize the misclassifications between the 1998 MRW "truth" map and the 2001 IFMAP LULC map. The error matrix comparison and analysis helped to "provide an effective way to accurately represent map accuracy in that the individual accuracies of each category are plainly described along with both errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the classification" (Congalton and Green, 1999). There was also a goal to better understand the specific circumstances where specific AAP locations were misclassified.

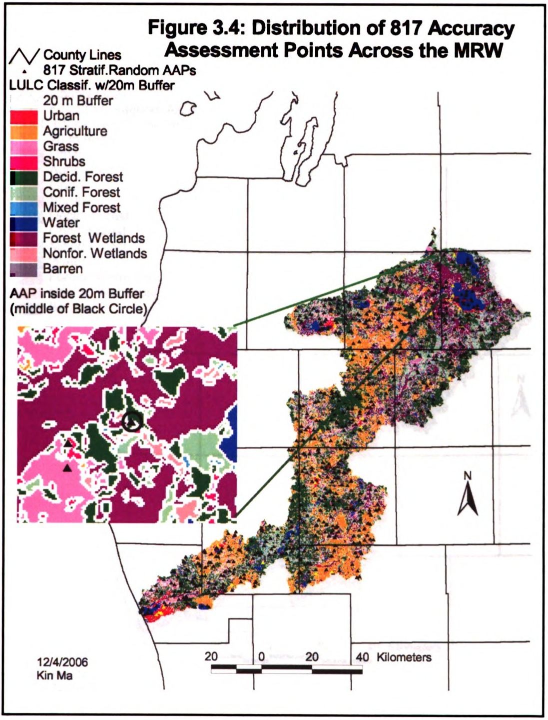


Figure 3.4: Distribution of 817 Accuracy Assessment Points Across the MRW
County Lines
817 Stratif.Random AAPs
LULC Classif. w/20m Buffer
20 m Buffer
Urban
Agriculture
Grass
Shrubs
Decid. Forest
Conif. Forest
Mixed Forest
Water
Forest Wetlands
Nonfor. Wetlands
Barren
AAP inside 20m Buffer (middle of Black Circle)
N
20 0 20 40 Kilometers
12/4/2006
Kin Ma

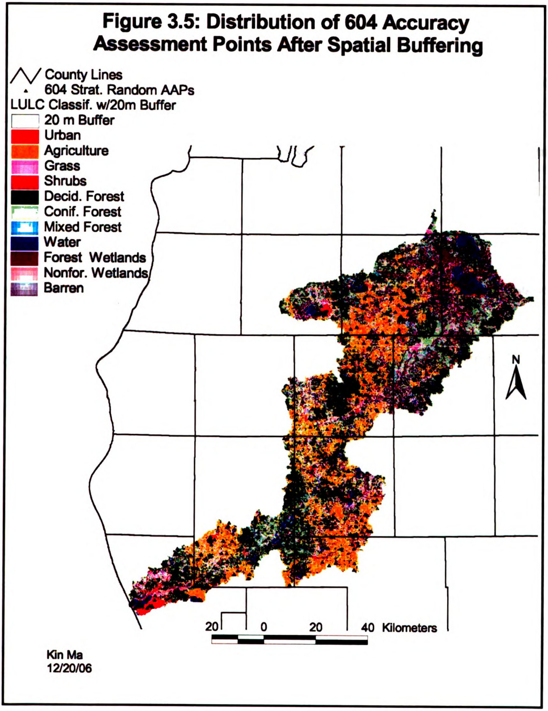


Figure 3.5: Distribution of 604 Accuracy Assessment Points After Spatial Buffering
County Lines
604 Strat. Random AAPs
LULC Classif. w/20m Buffer
20 m Buffer
Urban
Agriculture
Grass
Shrubs
Decid. Forest
Conif. Forest
Mixed Forest
Water
Forest Wetlands
Nonfor. Wetlands
Barren
N
20 0 20 40 Kilometers
Kin Ma
12/20/06

3.3.4. Classification Uncertainty

Land Cover Dependency Analysis

Spatial accuracy was not the only concern for classification accuracy analysis. Misclassified AAPs within each of the two error matrices between the 1998 MRW "truth" map and the 2001 IFMAP LULC map were analyzed and interpreted via spatial, temporal, spectral, and phenological considerations of the different LULC classes. Error matrix cells that had values of 5 AAPs or greater were selected for further review and analysis. This number of AAPs was chosen because it represents about 5.0% of the total number of misclassified AAPs from the 2001 IFMAP product. Error matrix cells with values less than 5 may have been anomalies or outliers and were de-emphasized in the individual error matrix cell analyses.

CHAPTER IV
RESULTS AND ANALYSIS

4.1. LULC Classification Comparison

4.1.1. 2001 IFMAP LULC Map

The LULC area comparison between the 1998 MRW "truth" map and the 2001 IFMAP product for each of the twelve land cover types is presented in Table 4.1 and graphically in Figure 4.1. The IFMAP classification was derived from a combination of Landsat TM and ETM+ scenes and utilized a clustering analysis that incorporated both an unsupervised ISODATA algorithm for the summer time images and also a supervised algorithm approach on some classes (Table 3.1). The difference between the total area classified as urban land cover by the 2001 IFMAP (222.4 km^2) compared to the 1998 MRW (522.0 km^2) is notable (Table 4.1). Since the IFMAP classification was based on spectral reflectance patterns, pixels associated with urban land uses (rather than cover) would tend to be underestimated. In areas of low-density residential housing, for instance, large backyards, front lawns and wooded land between neighboring houses would spectrally reflect a grass or forest land cover signal and these pixels would likely be classified as one of the vegetative classes and not the urban class.

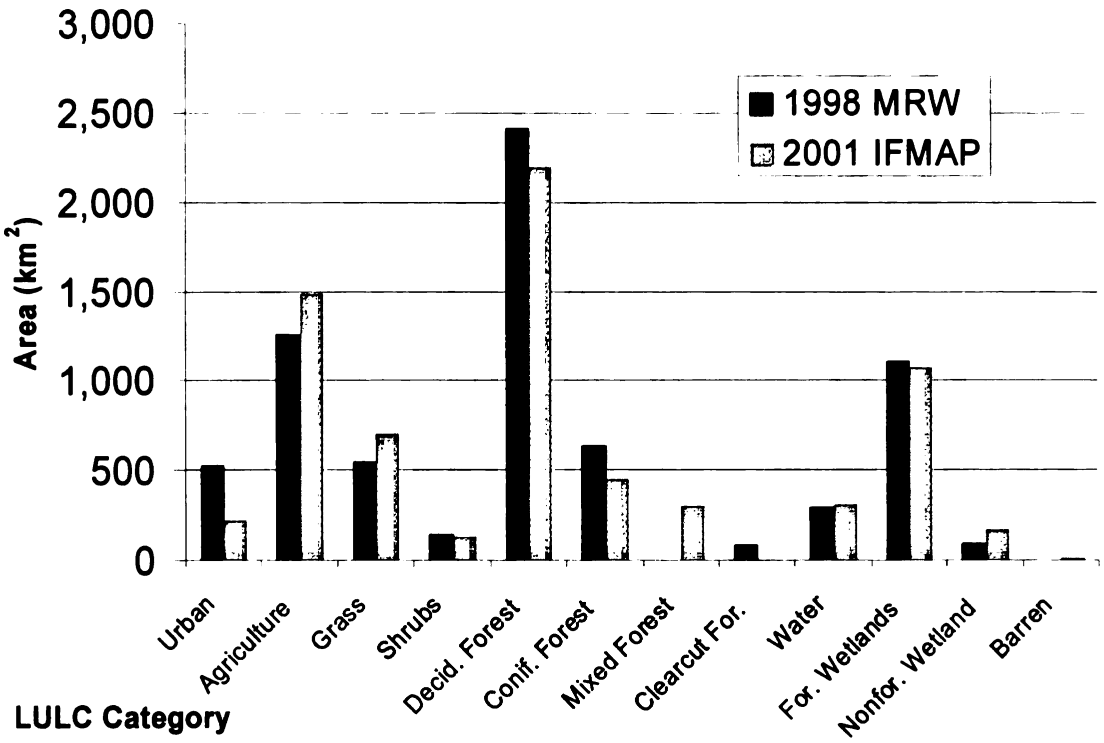
There were also some large areal differences between the 2001 IFMAP and 1998 MRW LULC maps, in which the 2001 IFMAP overestimated the areal extent of the agriculture, grassland, and non-forested wetland LULC categories. IFMAP classified 1,486.6 km^2 of the MRW in agricultural land, while the 1998 MRW classified 1,253.9 km^2 in the agricultural land class. IFMAP classified nearly 700 km^2 in grassland while the 1998 MRW classified 542.2 km^2 in grassland. For the non-forested wetland class, the IFMAP product classified 166.8 km^2 in this category, compared to only 90.4 km^2 in the 1998 MRW LULC map (Table 4.1).

Table 4.1: LULC Classification Comparison

LULC Class	1998 MRW	2001 IFMAP
Urban	522.0	224.4
Agriculture	1253.9	1486.6
Grass	542.2	699.9
Shrubs	142.5	131.1
Decid. Forest	2403.8	2196.9
Conif. Forest	635.6	454.7
Mixed Forest	1.7	301.3
Clearcut Forest	76.0	0.0
Water	288.1	307.1
Forested Wetlands	1099.9	1069.9
Nonforested Wetlands	90.4	166.8
Barren	1.0	11.4
Total Area (km2)	**7057.0**	**7057.0**

The 2001 IFMAP also underestimated the areal extent of the deciduous and coniferous forest LULC categories (Table 4.1). IFMAP classified 2,196.9 km^2 of the study area as deciduous forest, while the 1998 MRW had 2,403.8 km^2 in this class. IFMAP had 454.7 km^2 in the coniferous forest class, while the 1998 MRW had over 40% more area in this category (635.6 km^2). Finally, the remaining LULC categories of shrubland, water, and forested wetlands LULC categories had relatively equal areal estimates (Table 4.1).

Figure 4.1: LULC Classification Area Comparison

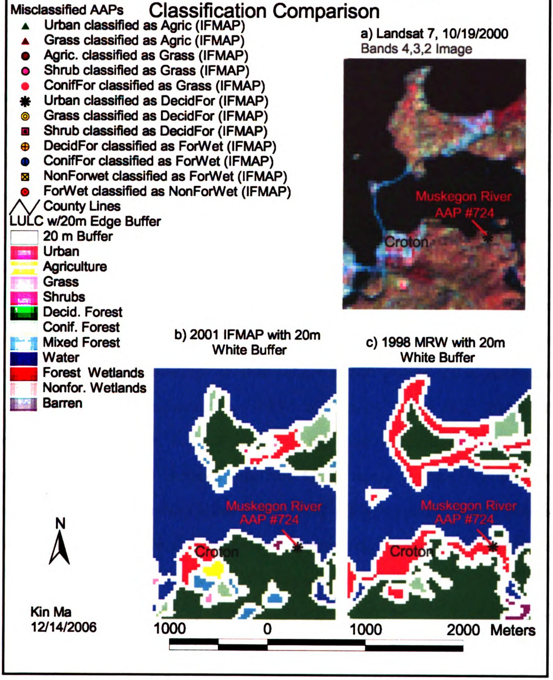


4.1.2. 1998 MRW LULC map

The 1998 MRW LULC map classified 522.0 km^2 as urban land -- more than twice the urban area as classified by the 2001 IFMAP product (222.4 km^2). The 1998 MRW classification relied on the definitions of the Michigan LULC Classification system (RS & GIS, 2002) and visual interpretation of color infrared aerial imagery. When closed canopy forest and grassland occurred in the urban built areas, the Michigan system assigns those regions to the "urban" class. Therefore, within the urban land use setting, the 1998 MRW map prioritizes the classification of land <u>use</u> over land <u>cover</u>, because residential grassy fields, and backyard forests, would be classified as 'urban' land use. Because of the definition of this classification system, it tended to classify more areas in the urban category. On the other hand, the 2001 IFMAP classification system classified by multi-spectral reflectance patterns. The land cover of a low-density residential area, for example, is dominated by the vegetative reflectance from the trees and grass, not the small reflective signal from the roofs of the houses or the driveways.

One example of this land cover vs. land use problem can be observed near the town of Croton along the Muskegon River (Figure 4.2). The 1998 MRW LULC map near AAP #724 classified the shoreline area as 'urban' while the IFMAP LULC map classified the entire area as deciduous forest.

Figure 4.2: IFMAP v. 1998 MRW Urban Classification Comparison



4.2. 2001 IFMAP/1998 MRW Error Matrix Analysis and Buffer Zone Method Development

4.2.1. Error Matrix Analysis

Classification accuracy with the entire set of 817 stratified random AAPs was performed when the buffer zone of spatial misregistration between the two LULC maps was not taken into account. The statistics in Table 4.2 shows the comparison of classification accuracy between the 1998 MRW and the 2001 IFMAP by utilizing 817 stratified random AAPs. The overall classification accuracy is 68.79% (kappa = 0.627). When the 817 AAPs were overlaid onto the 2001 IFMAP LULC map, 213 of these AAPs landed within the 20m spatial misregistration buffer zone (Figure 3.4). After eliminating these 213 AAPs from the 20m buffer zone, 604 stratified random AAPs remained (Figure 3.5). When accuracy assessment was run on this subset of 604 points, the classification accuracy percentage increased by 9.85% to 78.64% (Table 4.3). These 604 stratified random AAPs did not reside in the 20m uncertainty zone due to spatial misregistration between the two LULC maps. Hence, the thematic accuracy of the interior core areas of the LULC polygons on the IFMAP product is nearly 79% and the impact of spatial misregistration between the IFMAP and 1998 MRW maps could add nearly 10% apparent misclassification.

Without accounting for spatial misregistration, the 817 AAPs classification evaluation had only two LULC categories, water and barren classes, with conditional kappa coefficients equal to or greater than the industry standard of 0.85. Within this accuracy assessment (which includes the effects of misregistration), the classification of the grass, shrubs, and non-forested wetland classes performed very poorly with conditional kappa coefficients below

0.40 (Table 4.2). The grass and shrubland categories generated conditional kappa coefficients less than 0.25. The mixed forest category only had seven AAPs, so its near-zero conditional kappa score may not be meaningful.

When the effects of spatial misregistration were minimized, such as in the 604 AAPs accuracy assessment, two additional LULC classes, Urban and Coniferous Forest generated conditional kappa coefficients that exceeded 0.85 (Table 4.3). Nearly every Conditional Kappa for each LULC type improved in the 604 AAPs comparison, except the "Mixed Forest" class. The polygon sizes of Mixed Forest stands were very small, so that 4 out of 7 AAPs from the 817 AAPs classification accuracy assessment were eliminated since they had landed in the spatial misregistration buffer zone. As explained above, this small sample size renders the near-zero kappa score for Mixed Forest meaningless.

For the 604 AAPs classification accuracy comparison, the role of spatial misregistration between LULC maps was eliminated by utilizing the SPATIALM_BUFFER protocol. The overall classification accuracy increased to 78.64% (kappa = 0.742), which more clearly reflects the core thematic accuracy of the IFMAP product. Nonetheless, this accuracy (at Level I/II) is still 9.1% lower than Michigan DNR's reported 87.7% classification accuracy for IFMAP at the Level II classification (Michigan DNR, 2004). Despite the elimination of the role that spatial misregistration may have on accuracy assessment, the IFMAP overall classification accuracy remains below the 85% industry standard.

Within the 817 AAPs classification accuracy comparison, there were 255 AAPs within the 2001 IFMAP LULC map that were misclassified (31.2% of the total AAPs). 213 of these 255 AAPs (83.5% of the total misclassified AAPs) were located within the 20m spatial misregistration uncertainty zone. In a heterogeneous landscape like the Muskegon River Watershed, these data indicate that the deleterious impact of spatial misregistration during accuracy assessment can be substantial and must be addressed to gain a better understanding of core thematic accuracy.

Table 4.4 displays the error matrix for the 2001 IFMAP LULC map product using all 817 AAPs (i.e., misregistration noise is included). A total of 255 of the 817 AAPs were misclassified. The largest category of misclassified AAPs were the 20 Non-forested wetland AAPs from the 1998 MRW "truth" map, that were misclassified as forested wetlands in the 2001 IFMAP. The second largest number of errors of omission were 19 agriculture AAPs classified as grassland by the 2001 IFMAP. The largest urban class errors of omission (14 AAPs) were misclassified as agriculture. More detailed discussions for each of the highly misclassified matrix cells will occur in the following pages of the error matrix analysis.

With misregistration noise removed from consideration, the 604 AAPs error matrix (Table 4.5) displays some similarities in the categories of misclassified AAPs from the accuracy assessment of the original 817 AAPs. The largest number of misclassified AAPs are the 12 grassland errors of omission that were misclassified as agriculture by the 2001 IFMAP. The second largest number of misclassified AAPs are the 10 non-forested wetland errors of omission that IFMAP classified as forested wetlands. The third largest number of misclassified AAPs are the 9 agriculture errors of omission that IFMAP classified as grass. More detailed discussions for each of the highly misclassified matrix cells will occur in the following pages of the error matrix analysis.

Table 4.2: 2001 IFMAP Classification Accuracy (817 AAPs) BEFORE Buffer

Class Name	Refer. Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Urban	58	26	17	29.31%	65.38%
Agric	141	159	120	85.11%	75.47%
Grass	57	86	25	43.86%	29.07%
Shrubs	31	13	2	6.45%	15.38%
Decid For	239	238	197	82.43%	82.77%
Conif For	70	52	41	58.57%	78.85%
MixedFor	7	19	1	14.29%	5.26%
Water	53	55	51	96.23%	92.73%
For Wet	116	125	85	73.28%	68.00%
NFor Wet	35	33	13	37.14%	39.39%
Barren Land	10	11	10	100.00%	90.91%
Totals	**817**	**817**	**562**		

Conditional Kappa

Urban	0.6274
Agric	0.7036
Grass	0.2375
Shrubs	0.1205
Decid	0.7565
Conif	0.7686
MixedFor	0.0444
Water	0.9222
For Wet	0.6270
NFor Wet	0.3668
Barren	0.9080

Overall Classif. Accuracy =68.79% Overall Kappa = 0.627

Urban = Urban/Built up, Agric = Agriculture, Grass = Grasslands, Shrubs = Shrubland
Decid For = Deciduous Forest, Conif For= Coniferous Forest, MixedFor = Mixed Forest,
For Wet = Forested Wetlands, NFor Wet = Non-forested Wetlands, Barren = Barren Land

Table 4.3: 2001 IFMAP Classification Accuracy (604 AAPs) AFTER Buffer

Class Name	Refer. Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Urban	37	14	12	32.43%	85.71%
Agric	111	131	102	91.89%	77.86%
Grass	37	48	18	48.65%	37.50%
Shrubs	17	5	2	11.76%	40.00%
Decid For	175	184	162	92.57%	88.04%
Conif For	51	35	33	64.71%	94.29%
MixedFor	3	5	0	0.00%	0.00%
Water	53	54	51	96.23%	94.44%
For Wet	88	95	74	84.09%	77.89%
NFor Wet	22	22	11	50.00%	50.00%
Barren Land	10	11	10	100.00%	90.91%
Totals	**604**	**604**	**475**		

Conditional Kappa

Urban	0.8478
Agric	0.7288
Grass	0.3342
Shrubs	0.3826
Decid	0.8317
Conif	0.9376
MixedFor	-0.005
Water	0.9391
For Wet	0.7412
NFor Wet	0.4811
Barren	0.9076

Overall Classif. Accuracy =78.64% Overall Kappa = 0.742

Table 4.4: 2001 IFMAP v. 1998 MRW LULC Map Error Matrix (817 AAPs)

1998 Muskegon River Watershed LU Map

2001 IFMAP	Urban	Agric	Grass	Shrubs	Decid	Conif	MixFor	Water	ForWet	NFWet	Barren	Total
Urban	**17**	2	1	0	2	2	0	0	2	0	0	**26**
Agric	14	**120**	15	3	2	2	1	0	2	0	0	**159**
Grass	8	19	**25**	9	10	13	0	0	2	0	0	**86**
Shrubs	1	0	5	**2**	4	0	1	0	0	0	0	**13**
Decid	8	0	8	12	**197**	1	2	0	8	2	0	**238**
Conif	2	0	1	0	6	**41**	2	0	0	0	0	**52**
MixFor	3	0	0	1	7	5	**1**	0	2	0	0	**19**
Water	4	0	0	0	0	0	0	**51**	0	0	0	**55**
ForWet	0	0	2	3	10	5	0	0	**85**	20	0	**125**
NFWet	0	0	0	1	1	1	0	2	15	**13**	0	**33**
Barren	1	0	0	0	0	0	0	0	0	0	**10**	**11**
Total	**58**	**141**	**57**	**31**	**239**	**70**	**7**	**53**	**116**	**35**	**10**	**817**

Urban = Urban/Built up, Agric = Agriculture, Grass = Grasslands, Shrubs = Shrubland
Decid = Deciduous Forest, Conif = Coniferous Forest, MixFor = Mixed Forest,
ForWet = Forested Wetlands, NFWet = Non-forested Wetlands, Barren = Barren Land

Table 4.5: 2001 IFMAP / 1998 MRW LULC Map Error Matrix (604 AAPs)

1998 Muskegon River Watershed LU Map

2001 IFMAP	Urban	Agric	Grass	Shrubs	Decid	Conif	MixFor	Water	ForWet	NFWet	Barren	Total
Urban	12	0	1	0	0	0	0	0	1	0	0	14
Agric	10	102	12	2	0	2	1	0	2	0	0	131
Grass	3	9	18	5	3	10	0	0	0	0	0	48
Shrubs	0	0	1	2	2	0	0	0	0	0	0	5
Decid	5	0	5	6	162	0	2	0	3	1	0	184
Conif	0	0	0	0	2	33	0	0	0	0	0	35
MixFor	3	0	0	0	1	0	0	0	1	0	0	5
Water	3	0	0	0	0	0	0	51	0	0	0	54
ForWet	0	0	0	1	5	5	0	0	74	10	0	95
NFWet	0	0	0	1	0	1	0	2	7	11	0	22
Barren	1	0	0	0	0	0	0	0	0	0	10	11
Total	37	111	37	17	175	51	3	53	88	22	10	604

Urban = Urban/Built up, Agric = Agriculture, Grass = Grasslands, Shrubs = Shrubland
Decid = Deciduous Forest, Conif = Coniferous Forest, MixFor = Mixed Forest,
ForWet = Forested Wetlands, NFWet = Non-forested Wetlands, Barren = Barren Land

When the SPATIALM_BUFFER protocol was followed, AAPs were excluded from the 20m spatial misregistration uncertainty zone and only 102 AAPs were misclassified or 16.9% of the 604 AAPs (Tables 4.3 and 4.5). This group of 102 misclassified AAPs demonstrated that even after factoring out the influence that spatial misregistration has on accuracy assessment, other factors such as spectral differences, temporal and phenological issues, and classification system schemes, may also contribute to classification inaccuracy between these two LULC maps (Figure 4.3). These other factors will be explored in the pages below.

4.2.1.1. Misclassifications of Urban class AAPs

4.2.1.1a. Urban misclassified as Agriculture

There were ten AAPs within this error matrix category, and they occurred mostly in the central and southern regions of the MRW (Figure 4.3). In one example, north of Big Rapids along 19 Mile Road, the AAP #490 misclassification has been influenced by the likely spectral confusion between the reflectance of urban concrete and weathered asphalt and dry mineral soil within agricultural fields. During the late summer or early autumn period, agricultural fields that have been harvested may display considerable areas of bare soil. Bare mineral soil reflectance signatures often mimic the reflectance of urban asphalt/concrete features. As such, agricultural bare soil regions are often spectrally confused with true urban land cover regions. As shown in Figure 4.4, the 2001 IFMAP misclassified large tracts of the neighboring urban areas, particularly to the south of AAP #490 as agriculture. IFMAP's unsupervised classification algorithm performed on October, 2000 images clearly had difficulty distinguishing between true urban land use pixels and dry harvested agricultural plots.

Figure 4.3: Distribution of 102 Misclassified IFMAP AAPs

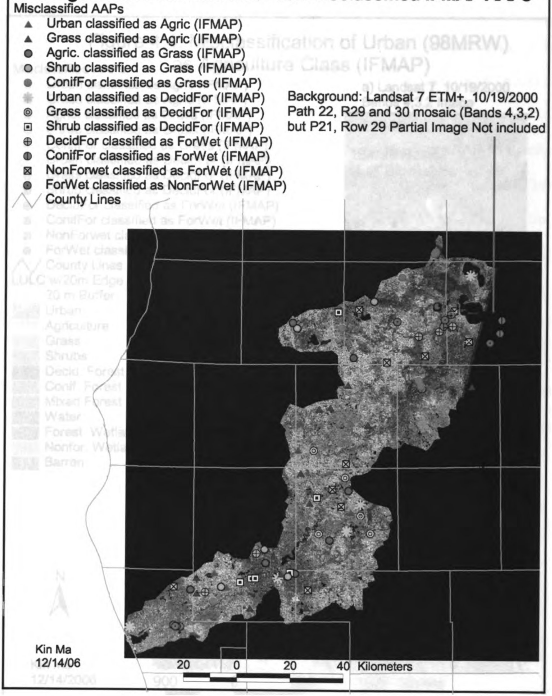
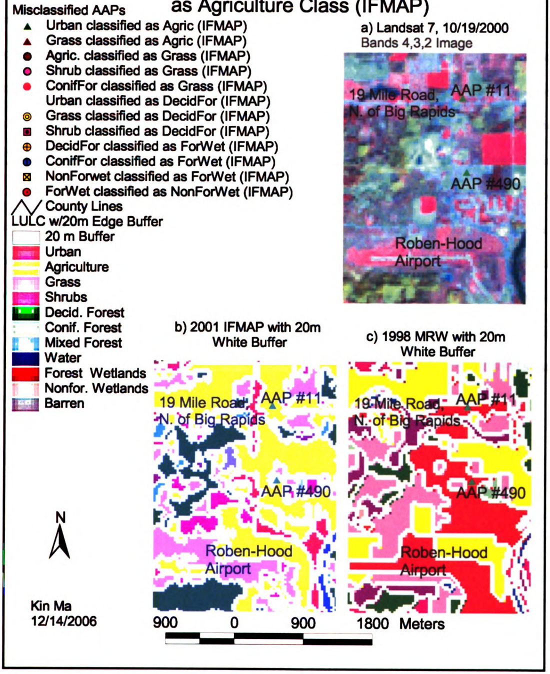


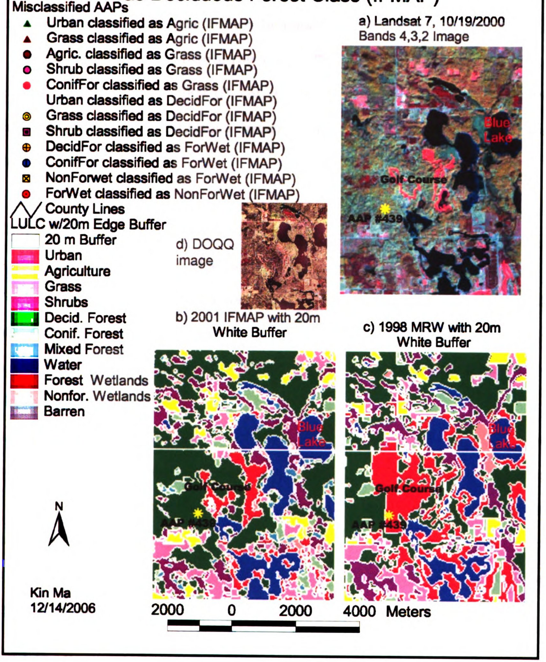
Figure 4.4: Misclassification of Urban (98MRW) as Agriculture Class (IFMAP)



4.2.1.1b. Urban misclassified as Deciduous Forest

Five of these misclassified AAPs occur near urban communities in the southern half of the MRW (Figure 4.3). For the first example, AAP #439, is located in central Mecosta County, west of the city of Mecosta. The point is very close to the edge of a golf course (Figure 4.5), which IFMAP correctly classified. Golf courses are members of the 'Outdoor Recreation" sub-category of the Level I (Urban/Built up) category. As shown on the 10/19/2000 Landsat image (Figure 4.5a), AAP #439 is surrounded by woody vegetation which is why IFMAP classified that area as deciduous forest (Figure 4.5c). This misclassification is undoubtedly the result of the difference between land use (1998 MRW) and land cover (IFMAP) and the inability of 30m Landsat imagery to resolve the street patterns of the woods (Figure 4.5d). The thin, white, horizontal lines crossing the datasets (Figures 4.5b, c) are artifacts of having divided the datasets into three sections to produce the 20m spatial buffer files.

Figure 4.5: Misclassification of Urban (98MRW) as Deciduous Forest Class (IFMAP)



4.2.1.2. Agriculture misclassified as Grass

Of the nine AAPs within this category, most were attributable to the land cover vs. land use problem. Grasslands can be spectrally similar to late-season agricultural fields because the brown biomass reflectance of the grassland is very similar to mature agricultural row crops. The 30m spatial resolution of the Landsat imagery use for IFMAP could not resolve the row structure to differentiate grassland (continuous brown biomass) from mature agricultural fields.

4.2.1.3. Misclassifications of Grass Class AAPs

4.2.1.3a. Grass misclassified as Agriculture

Twelve grass AAPs were misclassified as agriculture by the 2001 IFMAP (Table 4.3). The spectral similarity of grasslands and agricultural fields discussed above has also adversely affected the proper classification of the AAPs within this error matrix cell.

AAP #762 within Figure 4.6 is an example where the IFMAP classified most of the area west of Fremont Lake as agriculture. The 1998 MRW "truth" map was derived from 1m resolution color infrared (CIR) aerial photography which allowed small swaths of grass to be mapped within the sea of agriculture around it (Figure 4.6d). Such areas are not well resolved by the 30m Landsat imagery used for IFMAP.

4.2.1.3b. Grass misclassified as Deciduous Forest

Five Grass AAPs within this category were misclassified as Deciduous Forest within the IFMAP LULC map. AAP #549 presents an interesting circumstance because it is situated close to a grass/deciduous forest boundary. According to the IFMAP classification, AAP #549 sits squarely within a deciduous forest plot (Figure 4.7b), though when the position of the AAP #549 is plotted on the 1998 MRW map, it is located about 5m from the boundary between grass and deciduous forest.

Normally, after running the spatial misregistration buffer protocol, the boundary of each LULC polygon would be buffered 20 meters inside the polygon edge. However, in this case the corner of the deciduous forest polygon was an irregular polygon that had folded in on itself about a distance of 60 m on the right side and 120 m on the left side (see Figure 4.7(d) below). Since the polygon had inside edges, the transformation from a vector shapefile to this 20m inside buffer grid, on the "pink" grass side, produced some additional error. The buffer was only 20m wide, so that when the 20m buffer polygon shapefile was transformed into a 30m grid, the inside corner where AAP #549 was located, did not produce a 30 m pixel of deciduous forest but ONE isolated 30m pink pixel of 'grass' (Figure 4.7d). Because of the technical transformation from vector shapefiles to grids and then to Imagine images, AAP #549 fell on an isolated 'grass' pixel and appeared to be misclassified. This is one instance that the spatial buffering technique has not minimized the spatial misregistration of LULC map comparison. At this time, it is unclear why the spatial constraints selected within the ERDAS Accuracy Assessment module (section 3.3.2.) did not reject this one-pixel location. Further testing of this module is definitely warranted.

Figure 4.6: Misclassification of Grass (98MRW) as Agriculture Class (IFMAP)

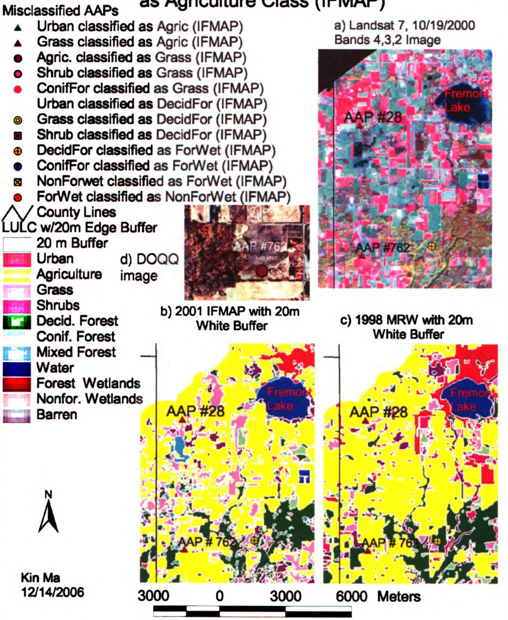
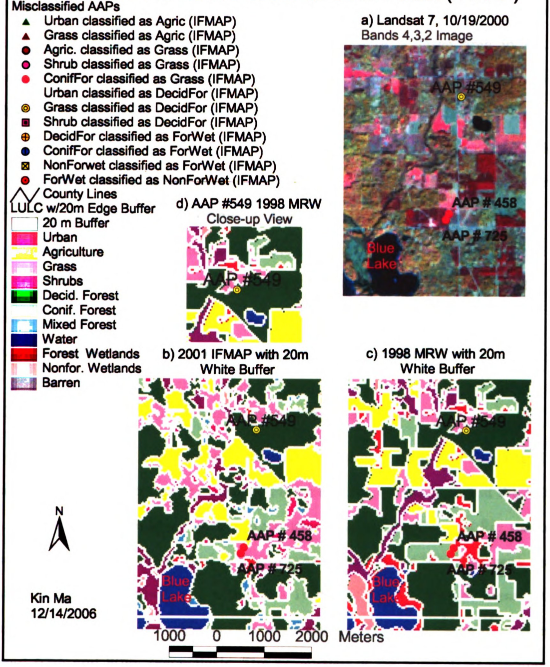


Figure 4.7: Misclassification of Grass (98MRW) as Decid Forest and Grass as Conif Forest (IFMAP)



4.2.1.4. Shrubland misclassified as Deciduous Forest

Six AAPs in this category were classified as deciduous forest in the 2001 IFMAP image. Four of these AAPs were positioned within the southern region of Newaygo County. Within the 1998 MRW map, there is large area in south central Newaygo County that spans an area of 4.2km x 4.3km in size that was labeled 'Shrub' (see Large Black circle in Figure 3.1). IFMAP classified most of this area, deciduous forest, and within the 10/19/00 Landsat ETM+ 10/19/2000 image, the reflectance values are very similar to the deciduous forest classified area to the northwest of the "shrub" area.

With the reflectance evidence from the Landsat imagery, this is likely one of the few locations in the 1998 MRW LULC map that is incorrect. In order to verify whether this is a true error, the original field check visits must be reviewed and perhaps new field visits may need to be conducted.

4.2.1.5. Deciduous Forest misclassified as Forested Wetlands

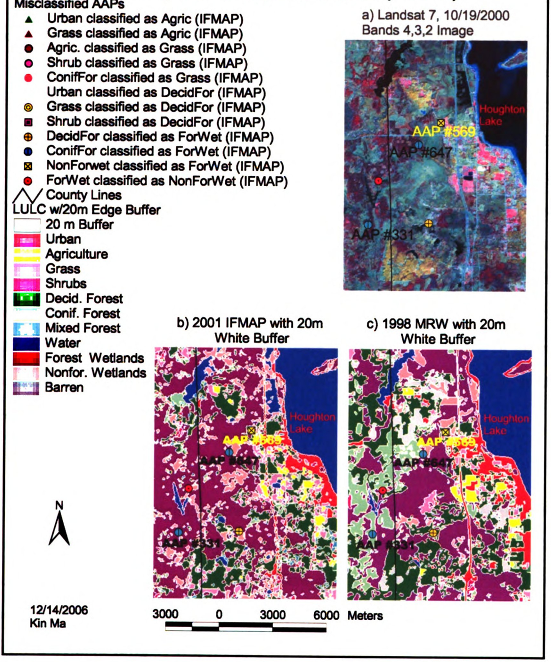
Five AAPs in this category were misclassified, two of these AAPs occurred in central Newaygo, and three of these AAPs were in the northern part of the MRW and found in Eastern Missaukee and western Roscommon County. For the two examples from eastern Missaukee County, AAPs #96 and #242, they were both classified as deciduous forest within the 1998 MRW map, though these AAPs were located close to the edge borders of an adjacent forested wetlands polygon, about 62m and 80m, respectively. The proportion of the three most prominent land cover types in this specific region was: 1) deciduous forest, 30%; 2) forested wetlands, 50%; and 3) coniferous forest, 20%.

When the AAPs were overlaid onto the 2001 IFMAP classification, it was clear that the IFMAP classification had overwhelmingly classified about 70% of this region's land as the Forested Wetlands category, and 20% in the deciduous forest and then 10% of this land as the non-forested wetland category. The Forested Wetlands category surrounded the areas around AAPs #96 and #242.

Nevertheless, the differences between the 1998 MRW and 2001 IFMAP, may be in the definition of forested wetlands. The Wetland category is a complex land cover type to define. Wetlands are "those areas there the water table is at, near, or above the land surface for the significant part of many year" (RS & GIS, 2002). Also, for the 1998 MRW classification, "two separate boundaries are important with respect to wetland discrimination: the upper wet boundary above which practically any category of land cover may exist" (RS & GIS, 2002).

The IFMAP LULC classification system defined "lowland forest classes as areas with evidence of flooding in the past five years and supporting lowland indicator species" (Michigan DNR, 2004). The IFMAP codes had divided their lowland forest classes into Level III types: 1) Lowland Deciduous, 2) Lowland Coniferous, and 3) Lowland Mixed Forest categories. However, at level II classification, these classes were re-assigned to Level II, "Forested Wetland" category (see Table 3.3). IFMAP LULC's category re-coding has likely caused these AAPs to be misclassified in eastern Missaukee County.

Figure 4.8: Misclassification of Conif. Forest (98MRW) as Forested Wetlands (IFMAP)



4.2.1.6. Misclassifications of Coniferous Forest Class AAPs

4.2.1.6a. Coniferous Forest misclassified as Grass

Ten AAPs were generated within this category and seven of these AAPs were located within forested regions in the northern half of the MRW. When viewing two examples near Blue Lake in central Mecosta County, AAP #458, and AAP #725 were located at the edge of a coniferous forest patch on the Landsat ETM+ 10/19/2000 Bands 4,3,2 composite image (see Figure 4.7a). The 1998 MRW classification indicated that the coniferous forest patch was wider than the 2001 IFMAP and had encompassed the region east of these two AAPs (Figure 4.7c), though within the 2001 IFMAP classification map, the spatial extent of the coniferous forest patch had decreased in size (i.e., forest cutting) and shifted west of AAPs #458 and #725 (Figure 4.7b). With this visual evidence and the different image dates of the 1998 MRW and 2001 IFMAP maps were derived from, 1998/1999 v. 2000/2001, respectively, **true** land cover change in this area explains these two misclassified AAPs.

4.2.1.6b. Coniferous Forest misclassified as Forested Wetlands

Five AAPs in this category were located in the northern section of the MRW just west of Houghton Lake (Figure 4.8). The misclassified AAPs #647 and #331 can be influenced by the definitional differences between the 2001 IFMAP and the 1998 MRW forested wetland classification schemes. As described above, the forested wetland category is a complex land cover type to define.

When AAP #331 was overlaid onto the 10/19/2000 Landsat ETM+ image, it was located within a coniferous forest patch as shown by the magenta colored reflectance from the Bands 4,3,2 composite image (Figure 4.8). The 1998 MRW classification followed the similar classification scheme and that small patch was indeed labeled coniferous forest. However, within the 2001 IFMAP classification, the "lowland coniferous forest" (Level III) category was re-coded to the "Forested Wetlands" Level II generalization (Table 3.3).

4.2.1.7. Forested Wetland misclassified as Nonforested Wetlands

Seven of these AAPs were misclassified in the IFMAP as Non-forested wetlands. Four of these AAPs were located in the Muskegon State Game Area northeast of Muskegon. Within the IFMAP LULC classification index of values, they define Non-forested wetlands as wetlands with "proportion of trees is less than or equal to 25% of land area," (MDNR, 2004), and therefore include a Lowland shrub category (IFMAP, Code #622, see Table 3.3). In the re-coding of the IFMAP LULC map and to maintain compatibility, the Lowland shrub category was re-coded to the **Forested** Wetland category (Table 3.3).

AAP #34, the furthest AAP to the west, is close to an adjacent Non-forested wetland category within the 2001 IFMAP, though the IFMAP LULC classified the entire region as Non-forested wetlands (Figure 4.9b), while the 1998 MRW map classified the same region as forested wetlands (Figure 4.9c). In the 10/19/00 image of the area (Figure 4.9a), there is evidence of low lying vegetation.

The 1998 MRW LULC map was derived from April 1998 Color infrared photography for early Spring, but the IFMAP Landsat images were dated in mid-autumn (10/19/00, 9/29/01). The temporal and phenologic differences of seasonal variation are some of the potential reasons for these four AAPs to be misclassified.

Figure 4.9: Misclassification of Forested Wetlands (98 MRW) as NonForested Wetlands (IFMAP)

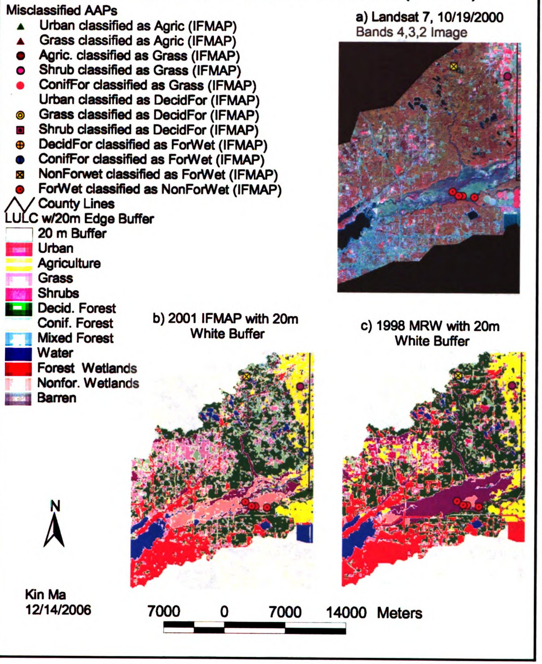
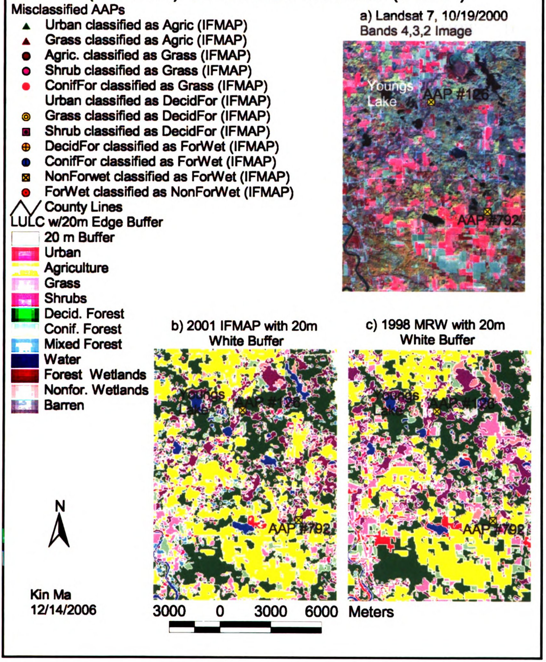


Figure 4.10: Misclassification of NonForested Wetlands (98 MRW) as Forested Wetlands (IFMAP)



4.2.1.8. Non-forested Wetlands misclassified as Forested Wetlands

Ten AAPs within this category were distributed across the MRW though five of these AAPs occurred in the northern third of the MRW. The two examples, AAPs #126 and #792, were located in eastern Mecosta County northeast of Big Rapids, in close proximity to Youngs Lake near the Haymarsh Lake State Game Area (Figure 4.10).

For AAP #126, the shape of the polygon that surrounds this point is very similar between the 1998 MRW and 2001 IFMAP classification maps. There was agreement regarding the spatial extent of this feature but relative heights of the vegetation may have influenced the non-forest v. forested wetland designation. Spring April 1998 imagery, vegetation may only begin budding though in the summer of early autumn period (10/19/00 Landsat image), vegetation in the same area would be full bodied and potentially influence the IFMAP interpreters to label this region forested wetlands.

4.3. Issues Affecting Classification Accuracy Assessment

The effects of spatial mis-registration have been largely reduced by the SPATIALM_BUFFER protocol, though a series of other variables have affected the overall classification accuracy percentage of 78.64% for the 604 AAPs comparison (Table 4.3). The summary of other variables that affected the classification accuracy of the 2001 IFMAP versus 1998 MRW MIRIS map comparison include differences in classification systems, scale issues, radiometric issues, phenological and temporal issues.

4.3.1. Classification System Issues

Researchers produce land cover maps and classify LULC according to their own purposes or to those of their funding sources. The 1998 MRW LULC map was based on the Michigan LULC Classification system and is the standard for Michigan LULC classification. On a given subject, the definition of specific concept or object must be clear to the reader and the audience in order to enhance mutual understanding and communication. If classification systems are not in agreement on the details of specific classification categories, confusion between classification systems may cause misclassifications of AAPs.

IFMAP had created a modified LULC classification system that were similar to the Michigan LULC system, though they had also assigned some categories that did not exactly match those of the 1998 MRW LULC (Table 3.3). For example, the IFMAP's Lowland Forest/Forested Wetland and Non-forested Wetland did not match up with the 1998 MRW categories. A total of 15 misclassified AAPs were due to classification definition differences. The 15 AAPs were misclassified in the following error matrix categories: Urban classified as

Deciduous Forest, Deciduous Forest classified as forested wetlands, and coniferous forest classified as forested wetlands. Thus, these errors totaled, 14.7% of the 102 misclassified AAPs for this study.

4.3.2. Scale Issues

The 1998 MRW MIRIS base map was initially a vector shape file with a 1 m resolution, and had a minimum mapping unit of 2.5 acres or 1 hectare (10,000 m^2). This vector file was aggregated and transformed into an ArcInfo grid file that had a 30 m resolution to match the resolution of the 2001 IFMAP LULC map. Spatial aggregation of data scales will lower the variance within the image and affect ratio variables such as elevation and biomass (Bian, 1997), though land cover classification type is a nominal variable. Therefore, the effects of aggregation of the image resolution from 1 m to 30 m would mostly affect the edges of land cover types, especially within the "urban" land cover category. At least one AAP, grassland misclassified as deciduous forest, was affected by this scale issue.

4.3.3. Radiometric Issues

Radiometric issues adversely influenced the misclassifications of regions where harvested agricultural fields exposed the bare mineral soil or when forests were clearcut and exposed the bare mineral soil of the forest floor. As stated earlier, the reflectance of bare mineral soil land cover type is very similar to concrete/asphalt features within the urban landscape. This issue primarily affected the grass AAPs misclassified as agriculture (IFMAP) and Agriculture (1998 MRW) AAPs misclassified as Grass (IFMAP). A total of 22 AAPs were adversely affected by these classification accuracy errors (21.6% of the 102 misclassified AAPs).

When evaluating misclassifications within these land cover categories, extra caution must be employed to determine whether the AAP is located within an agricultural row field crop or adjacent to an urban area. This issue affected primarily the agriculture AAPs misclassified as Urban, the Grass AAPs misclassified as agriculture in the IFMAP, and the grass AAPs misclassified as Agriculture. When evaluating misclassifications within these land cover categories, extra caution must be employed to determine whether an urban residential settlement was really built on the former forested plot or the location has bare mineral soil agricultural fields. Additional field research should be conducted to clearly ascertain the current true status of the land cover classification category.

4.3.4. Temporal and Phenological Issues

The images, from which the two LULC maps were based, play a large role in the misclassifications within the comparison error matrices. Table 3.2 displays the image inventory, the 1998 MRW LULC map was based on April 1998/ April 1999 aerial photo imagery, while the 2001 IFMAP LULC map was based on a series of Landsat TM and ETM+ scenes ranging from 10/19/2000 and 9/29/2001 (for fall vegetation senescence) and July 1999 and 2001 mid-summer images. There were a selection of points and small sections along the edge boundaries of agriculture and urban land use classes that showed true changes between the 1998 and 2001 image dates.

Since there was a difference of 2-3 years between the 1998/1999 MRW DOQQ images and the 2001 IFMAP Landsat TM and ETM+ images, the following land cover classes have the greatest probability for true land cover changes, e.g., agricultural fields converted to subdivision housing, forested lands converted to agriculture, grasslands growing back in an area where forested trees have been clearcut. There were sixteen misclassified AAPs that were affected by differences in phenology, and they consist of about 15.7% of 102 misclassified points.

In addition, these phenological differences mostly affected deciduous forest/forested wetland, and agriculture/grass land cover categories because of the growth rates of these vegetative classes during different times of the year. The different temporal images captured the extent of vegetative growth at only one point in time, and thereby causing the misclassification of these vegetative classes.

CHAPTER V
CONCLUSIONS AND FUTURE RESEARCH

5.1. Conclusions

Land Use/Land Cover classification accuracy assessment is a complex process. Misclassification or classification uncertainty can be affected by a large number of issues, such as the spatial mis-registration between the images being compared, phenological differences between the image dates and seasons, and potential spectral confusion of similar vegetated classes or other landscape characteristics within the satellite images.

5.1.1. Spatial Patterns, Magnitudes, and Land-Cover Dependencies of West-Central Lower Michigan LULC products

When initially comparing the 2001 IFMAP LULC map to the 1998 MRW map product, 817 stratified random AAPs were distributed across the 12 LULC types, and the result was overall classification accuracy of 68.79% (kappa=0.627). However, when the 817 AAPs were overlaid onto the 2001 IFMAP classification, 213 AAPs resided within a 20m spatial uncertainty buffer zone (26.1%). These 213 AAPs were removed, and the remaining 604 AAPs were used to assess the map accuracy and results showed that overall classification accuracy was 78.64% (kappa=0.742).

However, even after removing misregistration noise from consideration, 102 out of 604 AAPs were still misclassified (16.9%). The following land cover classes had the largest number of misclassified AAPs: grassland (12), urban/built up (10), coniferous forest (10), non-forested wetlands (10), and agriculture (9). Therefore, thematic misclassifications were still land-cover dependent and can be influenced by classification system, radiometric, temporal and phenological issues. These issues accounted up to a total of 55 misclassified AAPs, or 56% of the total 102 misclassified AAPs within the 1998 MRW and 2001 IFMAP error matrix evaluation for the Muskegon River Watershed in the west-central Lower Michigan region (Tables 4.3 and 4.5).

5.1.2. Spatial Misregistration Buffer Protocol Development

Classification accuracy assessment of different LULC maps is dependent on the sampling and distribution of accuracy assessment points (AAPs) across the spatial extent of the LULC map and stratified according to the requisite number of land cover types. In order to reduce the potential LULC misclassification of AAPs, due to them locating in spatial uncertainty zones within both the 1998 MRW and 2001 IFMAP LULC maps, a method of systematically buffering from the edge of LULC polygons was developed.

My study developed a spatial misregistration buffer protocol (SPATIALM_ BUFFER), to directly address this issue that has plagued many LULC comparisons up to this point in time. With the development of this relatively simple SPATIALM_BUFFER protocol, classification accuracy assessment issues related to spatial misregistration have been reduced to a minimum because the potential AAPs were excluded from being located within the zone of spatial uncertainty.

The development of this method protocol to create buffers equal to the combined spatial accuracy and spatial misregistration between the 1998 MRW and 2001 IFMAP LULC maps demonstrated that for the 2001 IFMAP dataset, 9.85% of overall classification accuracy, 78.64% minus 68.79%, was influenced by the spatial misregistration between the two LULC map products. Hopefully with the SPATIALM_BUFFER protocol, this method will increase the understanding of the classification uncertainty of LULC map comparisons and serve to move one step closer to developing an "uncertainty button" for our geographic information systems [software] (Foody and Atkinson, 2002).

5.2. Future Research

Within the 817 AAPs comparison, an alarming proportion of *stratified random* selected AAPs (83.5% of 255 misclassified AAPs, see Table 4.2) fell within the 40-meter-wide epsilon zone of spatial uncertainty. Presumably, the heterogeneous nature of the land cover/use in this test watershed contributed to this high proportion of near-edge samples. Further analysis of landscapes with different fragmentation regimes will be necessary to appropriately evaluate these stratified random sampling relationships.

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