Chapter 8
GIS and Remote Sensing Applications for Watershed Planning in the Maumee River Basin, Ohio

Kevin Czajkowski and Patrick L. Lawrence

Abstract The Maumee River watershed is the largest drainage basin that discharges into the Great Lakes. Although the watershed is largely a rural landscape, several major urban-industrial cities, including Fort Wayne and Toledo are located along the river. Many water quality concerns are present, especially non-point rural runoff that contributes significant amounts of sediment into the Maumee River. There is an important need to collect, organize and assess the available information on the watershed conditions and to better determine the status of the changes with land uses, crop rotation, and implementation of conservation tillage practices within this watershed. A partnership between the University of Toledo and US Department of Agriculture NRCS lead to several GIS and remote sensing products including annual land cover and crop rotations via remote sensing techniques, establishment of a Maumee Watershed Project Area GIS database, and providing educational and informational outreach with other project partners, resource managers, and the general public.

Keywords GIS • Remote sensing • Watershed planning

8.1 Introduction

The Maumee River watershed is the largest drainage basin that discharges into the Great Lakes. Although the watershed is largely a rural landscape, several major urban-industrial cities, including Fort Wayne and Toledo are located along the river. Many water quality concerns are present, including non-point rural runoff that contributes significant amounts of sediment into the Maumee River. There is an important need to collect, organize and assess the available information and better

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determine the status of the changes underway within the watershed. In 2005, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) entered into a five year agreement with the Geographic Information Science and Applied Geography (GISAG) Research Center at the Department of Geography and Planning at the University of Toledo, Ohio.

The work performed assists NRCS in undertaking sub-watershed rapid resource assessments, watershed and area planning, farm conservation planning, and delivery of conservation technical assistance and conservation cost-share programs authorized by the 2002 Farm Bill. The tasks undertaken with this project consists of: annually determining land cover and crop rotations via remote sensing techniques; combining Ohio, Indiana, and Michigan data layers to establish Maumee Watershed Project Area GIS database; and establishing a Maumee Watershed Project GIS Website to provide educational and informational outreach with other project partners, resource managers, and the general public.

The Western Lake Erie Basin has been identified by NRCS as a major contributor of non-point source pollution into Lake Erie. In 2005, NRCS developed a plan to use Rapid Resource Assessments, Area Wide Planning, and acceleration of USDA Farm Bill programs to address the resource concerns for the Western Basin of Lake Erie, and contributing watersheds including the Maumee, Portage, and Ottawa Rivers. This 10-year study primarily addresses land use/cover changes, conservation tillage practices, and water quality monitoring. A secondary element of this plan is to develop a basin wide GIS (Geographic Information System) to aid in watershed planning projects and public outreach. Nelson and Weschler's (1998) study suggested that the Maumee River watershed might not be ready for basin wide collaboration on watershed planning, but with the implementation of a GIS-based institutional atlas, the local and regional organizations and agencies with interests in watershed planning could be moving in the right direction towards integration.

The watershed management approach has emerged as a holistic and integral way of research, analysis and decision-making at a watershed scale (Montgomery et al. 1995; Perciasepe 1994; Voinov and Costanza 1999). Initially oriented toward the control of water supply and use, it has shifted to include a concern for water quality and the combined effects of land use in the drainage basin, particularly since non-point pollution has overtaken point-source pollution as a primary concern as a cause of impairment (Nelson and Weschler 1998). By relating water quality and land use concerns, a link is created between science and planning, thereby connecting all stakeholders, community leaders, agency administrators, and concerned citizens in the watershed. Basin-wide collaborations can provide the expertise, scientific backing, moral support, and political leadership necessary to implement regional plans. GIS interfaced hydrological models are considered as a major tool for surface water management at a watershed scale because they are capable of presenting the relationship between the spatial and hydrological features of the watershed in an efficient way (Al-Abed et al. 2005).

GIS is a general-purpose technology for handling geographic data in digital form (McKinney and Cai 2002). GIS has the ability to combine physical features, political and administrative jurisdictions, and organizational missions in order to make sound recommendations or decisions for the entire watershed. The advances of GIS have grown beyond simple data management, storage, and mapping. Today, a more sophisticated means of analysis is being utilized by combining various mathematical and computer generated models with spatial data within the GIS. Simulation models are useful tools for analysis of watershed processes and their interactions, and for development and assessment of watershed management scenarios (He 2003). Schreier and Brown (2001) used GIS for analysis of buffer zones, which were delineated and classified from digital aerial photos, which allowed the identification of the type, width and continuity of the buffer zone. Kelsey et al. (2004) used GIS techniques to calculate several "distance or proximity" land-use variables to examine land-use effects on fecal coliform densities.

In October 2005, NRCS entered into a five year memorandum with the Geographic Information Science and Applied Geography (GISAG) Research Center of the Department of Geography and Planning at the University of Toledo as part of the Western Lake Erie Basin Water Resources Protection Plan. The University of Toledo assisted NRCS in implementing the Maumee Watershed project, including sub watershed rapid resource assessments, watershed and area planning, on farm conservation planning and delivery of conservation technical assistance and conservation cost-share programs authorized by the 2002 Farm Bill. The tasks generally consisted of: annually determining land cover and crop rotations via remote sensing techniques; combining Ohio, Indiana, and Michigan data layers to establish Maumee Watershed Project Area GIS data layers for the project; and establishing and maintaining a Maumee Watershed Project GIS Website to provide educational and informational outreach to share data and information with other project partners, resource managers, and the general public.

Crop type classification for the Maumee River project is being carried out using multitemporal Landsat 5 satellite imagery for each year of the agreement. Images were gathered from several time periods during the growing season to differentiate between the different crops types, in particular corn, soybeans, wheat and pasture. Once collected, the images underwent cloud screening and then were stacked in Erdas IMAGINE remote sensing software package. Training sets of crop type had been collected using a driving survey of the watershed and located with Global Positioning System (GPS) readings. These training sets were used to create spectral signatures in Erdas and then a supervised classification was performed using the Maximum Likelihood classifier.

8.2 Maumee River Basin

The Maumee River basin covers over 4.9 million acres across Ohio, Michigan and Indiana. The Maumee River, the most prominent watershed in the basin, begins in Fort Wayne, Indiana, and extends more than 130 miles to Lake Erie, 105 miles of which are located in Ohio (Fig. 8.1). The Maumee River has the largest drainage area of any Great Lakes river with 8,316 square miles and drains some of the richest farmland in Ohio. The project area for this study will only include the drainage into

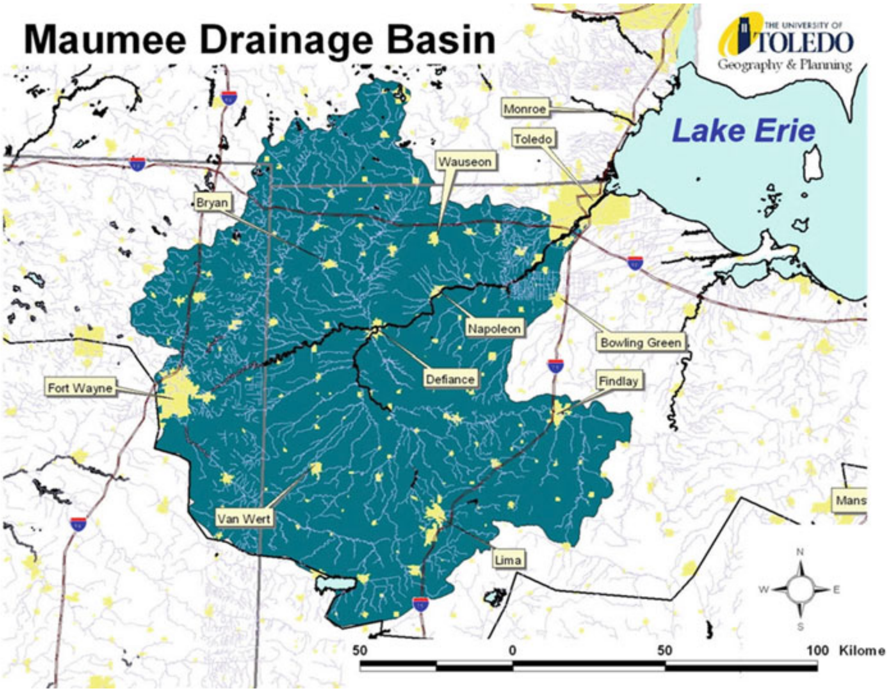

Fig. 8.1 The Maumee Drainage Basin, NW Ohio

Lake Erie south of the Ohio-Michigan state line. The cities of Toledo, Fort Wayne, and Lima constitute the major urban areas. Other smaller towns and cities are scattered throughout. The population of this area totals over 1.2 million people.

Land use is predominantly agriculture covering about 71% of the total basin (NRCS 2005). Urban development and roads represent 10% of the area (NRCS 2005). Soils are naturally poorly drained. Surface ditches and subsurface drains have been implemented to improve drainage. The basin area receives a relatively even distribution of precipitation throughout the year between 33 and 37 in. depending on the location. Soil erosion is a major problem in the basin causing NRCS to track conservation tillage practices in order to reduce the loss of sediment off cropland. Dredging in the Toledo Harbor, at the mouth of the Maumee River, is costing $2.2 million per year due to sediment loading. Tourism and sport fishing are also directly related to water quality and the health of the lake associated with increased sedimentation (NRCS 2005). Several watershed planning efforts have been undertaken with the Maumee Basin, especially in the Maumee Great Lakes Area of Concern (AOC) located in the lower (downstream) portion of the Maumee River and including several other rivers and streams discharging directly into the western basin of Lake Erie (Lawrence 2003; Maumee RAP 2006).

Table 8.1 Main GIS data layers for the Maumee GIS Project

DEM (Digital Elevation Model)
SSURGO soils
Stream network
Land use cover
Watersheds (HUC units)
Quaternary and bedrock geology
Recreational areas and parks
Various boundaries (states, cities, and counties)
Wetlands
Source water protection areas
Groundwater data
100 year floodplains
Climatic zones
Soil drainage
Roads and transportation

8.3 GIS Database Development

Spatial data layers were assembled from numerous sources to assemble and deliver GIS layers that cover the entire Maumee Watershed Project Area (Table 8.1). Some of the websites, where spatial data is freely available, are Soil Data Mart, Data Gateway (NRCS/USDA), Center for Geographic Information in Michigan, ODNR GIMS (Geographic Information Management Systems), Indiana Geological Survey (A GIS Atlas), United States Geological Survey (USGS), and Great Lakes Information Network (GLIN). Once the data was downloaded, it was necessary to evaluate its condition using ESRI ArcGIS software. Datasets for the basin needed to cover Ohio, Michigan, and Indiana. In some cases, there was only Ohio datasets available and therefore were not used. In other cases, there were security issues; therefore the data was not made public. Metadata, which contains descriptions of the spatial data sets, needed to be present because it indicates what has been done to create the data and who created it. The metadata would be updated with the project purpose and contact information. After deciding on datasets, geoprocessing techniques were performed. Clipping, merging, and reprojecting were necessary for datasets for map overlay.

The next step was to establish a GIS website for the Maumee Watershed Project Area linking an ArcIMS site for data viewing. The website located at www.maumee.utoledo.edu contains background information on the project, spatial layers available for download through a password protected ftp site, and the ArcIMS available for viewing these spatial layers (Fig. 8.2). The ability to download the information is a means to share the data with NRCS and project partners for the overall collaboration of the project. Training sessions were held for partners and stakeholders to learn how to use this online system providing them ample opportunity to make suggestions and ask meaningful questions.

ArcIMS provides for the ability to access various layers at various scales of viewing. In this manner it is possible to compile many important spatial data layers into the GIS product and make each layer viewable and active at the appropriate scale.

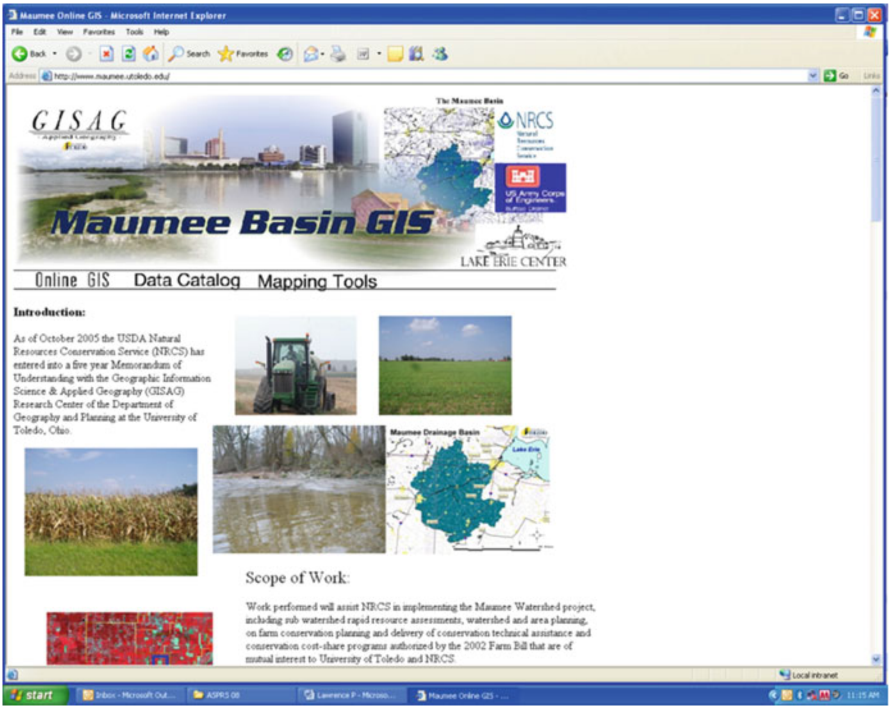

Fig. 8.2 Maumee GIS project website (at www.maumee.utoledo.edu)

For example, Fig. 8.3 shows the view scale of the entire watershed area highlighting the individual river basins located within the watershed with additional layers including land use/land cover, 2005 NIAP imagery, ecoregions and state boundaries. Figure 8.4 illustrates a view at the scale of one river basin with display of the Land Capability Class and additional layers that include counties, zip codes, annual precipitation, farmland class and many others. Figure 8.5 displays the view at the local community scale highlighting SSURGO soil types and also can include Census blocks, streets, and several other additional data layers. ArcIMS also provides numerous data tools to assist with spatial analysis including query functions, distance calculations, and area measurements – all of which can be useful to potential users of the datasets.

8.4 Remote Sensing

Land cover and land use can be classified for a watershed region by utilizing a satellite image which covers a large area. Landsat Thematic Mapper can be used at the regional level with its 30 m spatial resolution (Oetter et al. 2000; Jensen 2005;

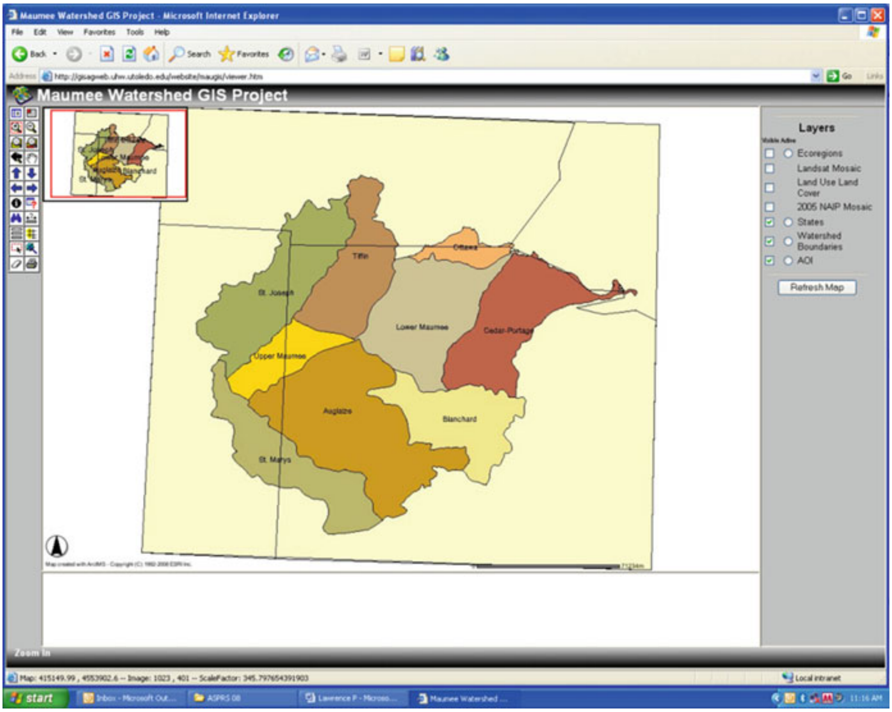

Fig. 8.3 Screenshot of Maumee Watershed layer showing all river basin units

Woodcock et al. 2001). The point of classification with remote sensing is to categorize every pixel in the image into themes or classes based on the reference spectral response of a band. Normally, multispectral data is applied since categories which can be separated in a channel are very limited. A commonly used method is the supervised classification technique which requires a prior knowledge of the study area, and pixels are classified based on the user-defined reference spectral data set. A maximum likelihood is used to categorize the pixels into defined classes as it takes into account a variance and a covariance to the computation and classifies pixels into a class to which the pixel has the highest probability of belonging (Jensen 2005).

Many times a good classification of land cover types can result from applying a single image. However, when land use types such as crop types are classified, it is useful to use multiple images wherein the dates are different. In the case of crop identification, the images include pre-growing season and growing season so that different spectral information can be extracted from the images which discriminate objects in the study area. For instance, winter wheat may be indistinguishable from bare soil in late fall when it is just planted and from alfalfa in spring due to a similar spectral response. However, by using two images, winter wheat can be identified by having a unique set of responses to bare soil in fall and alfalfa in spring (Lillesand et al. 2004). Therefore, it is important to know the study area to take advantage of the multi-temporal classification.

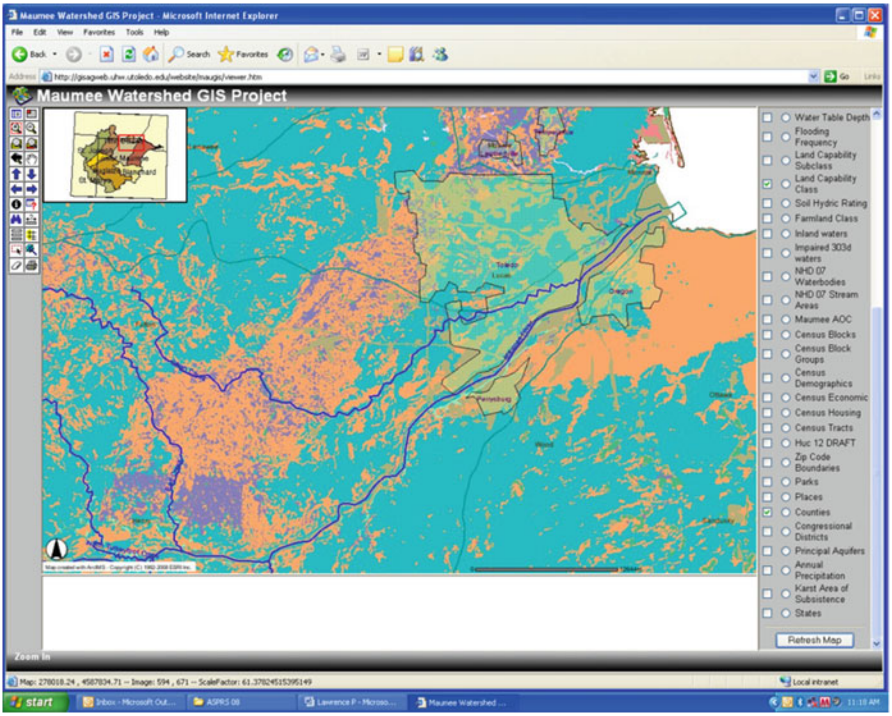

Fig. 8.4 Screenshot of Maumee GIS ArcIMS product as viewing one river basin and highlighting the land capability classification layer

A land use and land cover layer was created for this study. Throughout the creation of the classified map, ERDAS IMAGINE 9.1 was utilized unless otherwise noted. Ground truth points were collected at selected transits along roadways within the watershed resulting in over 300 points annually for analysis. Landsat TM images of path 20/row 31 were used for the classification which were downloaded from the OhioView website. Clouds and shadows in the images were removed by visual assessment. Removal of the urban area was also conducted by visual assessment using an urban area shapefile downloaded from the ESRI Census Watch website (http://www.esri.com/censuswatch). The images were then stacked to perform the multi-temporal classification. For example in 2005 images were used from May 4th, August 8th, and November 12th in order to cover the complete growing season for the primary crops: corn, soybeans and wheat.

The identification of crop types within farm fields was also checked by USDA personnel at the county level within the watershed on an annual basis via "windshield surveys" that would generate 8,775 observation points. Among these crop type observations, 78% were either corn or soybean. At total of 150 points per class for the entire Maumee watershed were randomly selected as reference points, and the others were used as training samples. Out of the 150 points, 75 points per class

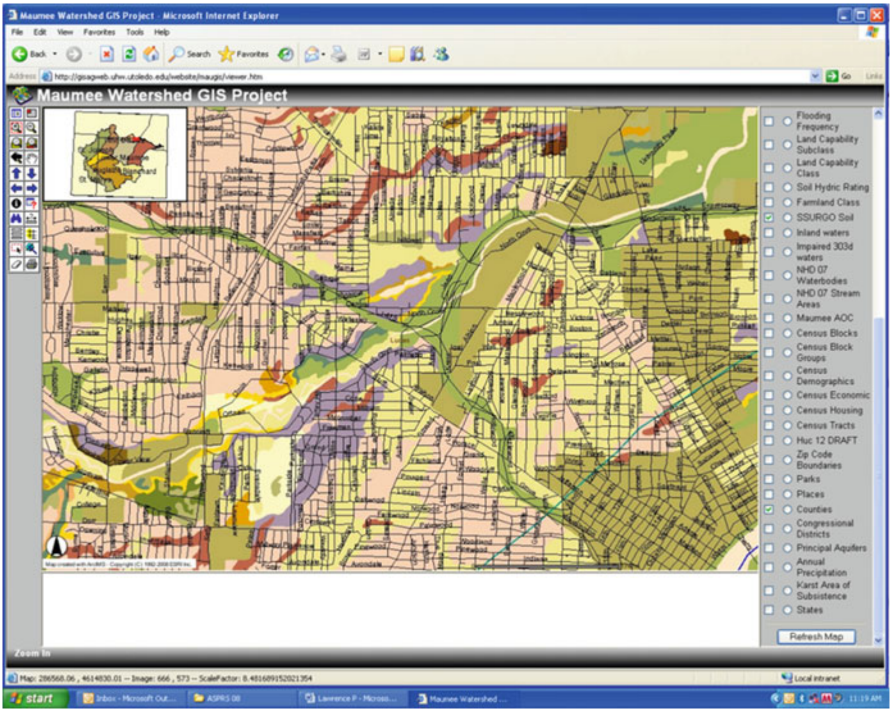

Fig. 8.5 Screen shot of Maumee GIS ArcIMS product as viewing at the community scale and highlighting the SSURGO soils layer

fall into the study area and were used for accuracy assessment of the supervised classification for the study area. Normally, a minimum of 50 samples for each class is good enough for the accuracy assessment. However, when a study area is larger than one million hectare, the minimum number of the sample should be increased to 75 or 100, thus for this study, 75 samples were used.

To perform a maximum likelihood supervised classification, a training set for each class of corn, soybean, hay, and wheat was created. By using the training samples, pixels were selected by using an Area of Interest (AOI) tool for each class. The training samples were visualized in different colors in terms of cardinal directions to consume less effort and time in collecting pixels. For each class, about 100 fields of pixels were collected. Those pixels were the reference for the computer to classify the entire image. For the forest and water classes, pixels were collected visually. Water is obvious in a satellite image by its shape and color of navy to light blue with bands 4, 3, and 2 as red, green, and blue in color composite. Forest is also visible and easily identifiable in an image by its texture and color of red with the same condition of the color composite as that used for the water.

After running the supervised classification, sieve and clump functions of ENVI were applied to the classified image except for the water and forest classes to smooth isolated pixels. The sieve function identifies an isolated pixel, and the clump function classifies the isolated pixel into the class which has the highest occurrence of its surrounding pixels. Some water bodies such as a river and some forest which are represented by a pixel or line of pixels were likely to be removed by the sieve-clump process, therefore the original water and forest classes were reserved.

Finally, an accuracy assessment was conducted for the classified image by using the reference points, which were separated from the training sample at the beginning. The reference points were compared with the classified map to check to see if the reference field was classified correctly or not in ArcMap with the cardinal directions of the reference point visualized in a different color. This information was typed into Excel, which has columns of reference point numbers and classified classes. For the forest and water class, random points were created by an accuracy assessment function, and they were visually assessed by using the satellite image with the color composition used for the creation of the training set described earlier in this section.

An error matrix with columns of reference classes and rows of classified classes was created. By using the matrix, overall accuracy was estimated by dividing the total amount of diagonal pixels by the total amount of all of the pixels used for the accuracy assessment. An accuracy of 85% or more overall accuracy is considered acceptable. The accuracy of each class was estimated. A producer's accuracy or an omission was calculated by dividing the total number of the correctly classified pixels in a certain class by the total number of pixels of that class derived from the reference data. A user's accuracy or commission errors is calculated by dividing the total number of correctly classified pixels in a certain class by the total number of pixels of that class derived from the classified data and tells how much the classified pixels match with the actual validation points. A further assessment was performed by conducting a kappa analysis, which indicates the accuracy between the classified map and the reference data and if accuracy was derived from an actual agreement between the two data or by chance. Actual agreement would be strong with a kappa value of more than 0.80, fair with a value between 0.80 and 0.40, and poor with a value below 0.40.

An example of an annual land cover/land use and crop type classification (from 2005) is shown in Fig. 8.6, with farmland with planted crops the most common land cover/land use. Soybean (47%) and corn (18%) crops are the most common rural land use/land cover types. Forest cover was found to represent 17% of the land area. The reference points of hay and wheat were small due to the limited amount of the ground truth points. Overall accuracy of the classification was 87.96% and the Kappa value was 0.82.

Tillage classification was conducted in the same way as the crop types were classified. For example the tillage classification in 2006 used a Landsat TM image of path 20/row 31 acquired on May 23, 2006 and obtained from the OhioView website. The classes created for the map were traditional tillage (<30 %), mulch-till (30–90 %), no-till (<90 %), forest, and water. Tillage systems within the Maumee watershed were documented at 8,927 farmfield data points that were checked by USDA personnel at the county level. Approximately ½ of the farm field points were

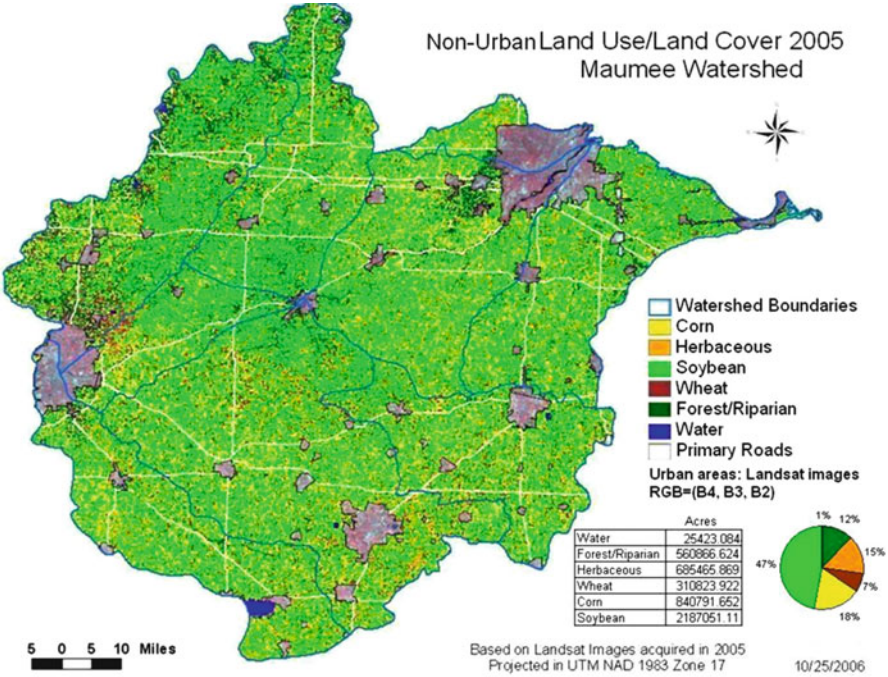

Fig. 8.6 Land cover/land use classification with crop types, 2005

found to represent no-till agriculture in the watershed. An accuracy assessment was also conducted, and an error matrix was created. The resulting image of the supervised classification conducted for the tillage systems in 2006 is shown in Fig. 8.7. The accuracy was 81.33% and did not reach the acceptable guideline. However, it was the best result which was performed, and the technique was utilized for the remaining annual classification and mapping of tillage with similar results. The Kappa value was 0.77, with the agreement between the classification map and the reference data fair enough and close to a strong relationship, and the accuracy of the classification was less likely to happen by chance.

8.5 Discussion

With the development of the Maumee GIS/Remote Sensing project several data gathering issues have been identified. Data may have been found for only one or two states and not complete for the entire Maumee Basin. Some contacts were not willing to share their data due to copyright or propriety issues. Some data is not being made public because of security reasons such as transportation, pipeline, and other infrastructure. For many of the GIS datasets no metadata attached to data

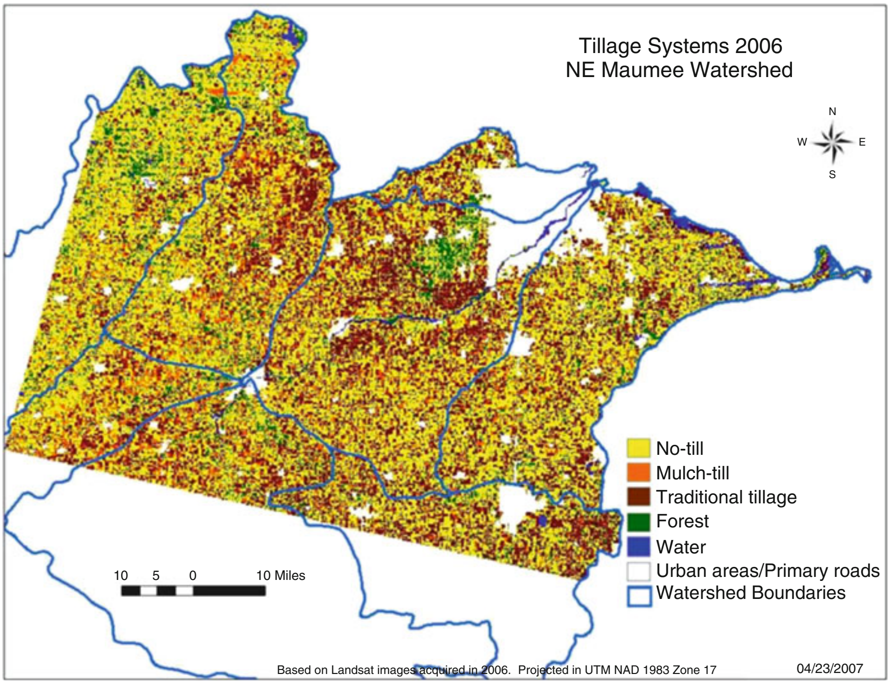

Fig. 8.7 Classification of Tillage Systems in the northeast portion of the Maumee Watershed, 2006

sets making it very difficult to validate and assess the data source and its quality. The development of the spatial database is a continuing process. Feedback from users of the ArcIMS web based viewer is helpful in managing the website in order to make it more user friendly. Efforts continue in the updating of data sets with current information.

In early 2007 a survey was sent to 188 current and potential users of the Maumee Basin GIS/Remote Sensing project website (www.maumee.utoledo.edu) in order to assess the utility of the website and ArcIMS data viewer and to solicit feedback on future additions and improvements (see Rousseau, this volume for more details). A total of 55 individuals responded (29% return rate) with state and federal government agencies and NGOs/Universities having the largest number of respondents. Over 41% of respondents indicated that they had been using GIS for more than 5 years. When asked about their use of GIS in watershed planning 60% indicated that they had created maps or data products and the most common sources of GIS data that they used included the Ohio Department of Natural Resources (ODNR) GIMS website, USGS, and NRCS Service Data Gateway. In accessing and using the Maumee Basin GIS/Remote Sensing project website over 90% rated the site as Good to Excellent and suggested improvements, including making more data readily available for download, providing clearer instructions for non GIS users, and providing links to metadata and source citation.

Ongoing searches are underway to secure and post additional new useful data sets and work continues in evaluating current data sets. Additional updates to the data sets during the project included transet data collected annually from 2007 to 2009 on crops types for use as validation/training data for land cover analysis, assembling data sets in response to severe flooding and impacts along the Blanchard River in August 2007, collection of the Landsat imagery for 2007–2009 for the preparation of a series of annual land use, crop type and tillage analysis, acquisition of one foot orthophotos for the watershed, collection of the NAIP and LiDAR imagery available for a portion of the Maumee Basin. Tasks also included compiling the field survey data from 2007 to 2009 for crop type and tillage assessments collected by NRCS county extension staff into a common database, analysis of annual land cover from Landsat (including accuracy assessment and % cover types), development of tile surface creation workflow to assist in creating a bare earth DSM, and to process the LiDAR and NAIP imagery into ArcIMS.

8.6 Conclusions

The Maumee GIS/Remote Sensing Project has created an array of useful products to assist with various watershed planning initiatives underway within the basin including projects undertaken by the Western Lake Erie Basin Partnership, USDA NRCS, and Army Corp of Engineers. The GIS database has been provided on request to various parties to assist with the preparation of watershed studies, rapid assessments, crop inventories, sediment modeling, and in response to flooding events. As further progress is made in determining the critical watershed issues and prioritizing future projects, programs and efforts within the basin, the GIS and remote sensing materials will be of continued importance. The project website, with GIS data layers and the land use/land cover mapping from remote sensing, provides many important opportunities for public outreach, teaching and the creation of unique map based products for a variety of watershed projects within the Maumee Basin. With the ongoing development of watershed based planning within the Maumee Basin by a variety of agencies and organizations these spatial data sources will be increased value in plan development.

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