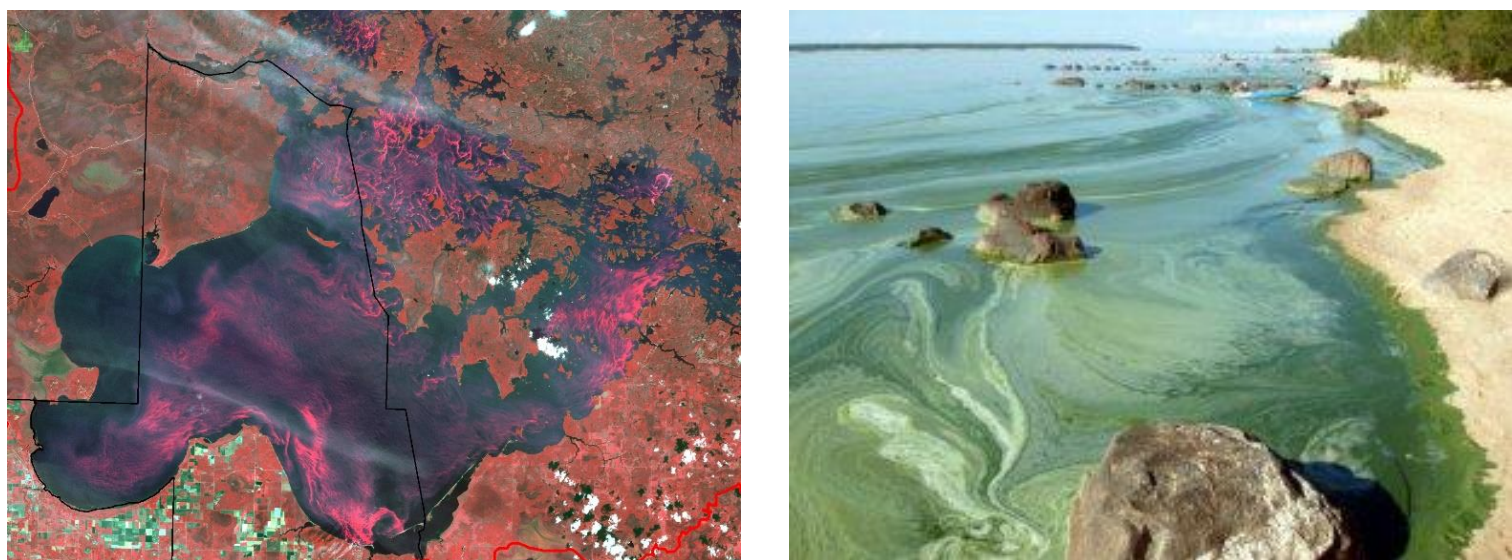


Improved Land Cover Classification by Integrating Landsat Imagery with Lidar and Object-based Image Analysis for Land Cover Classification of the International Lake of the Woods/Rainy River Basin

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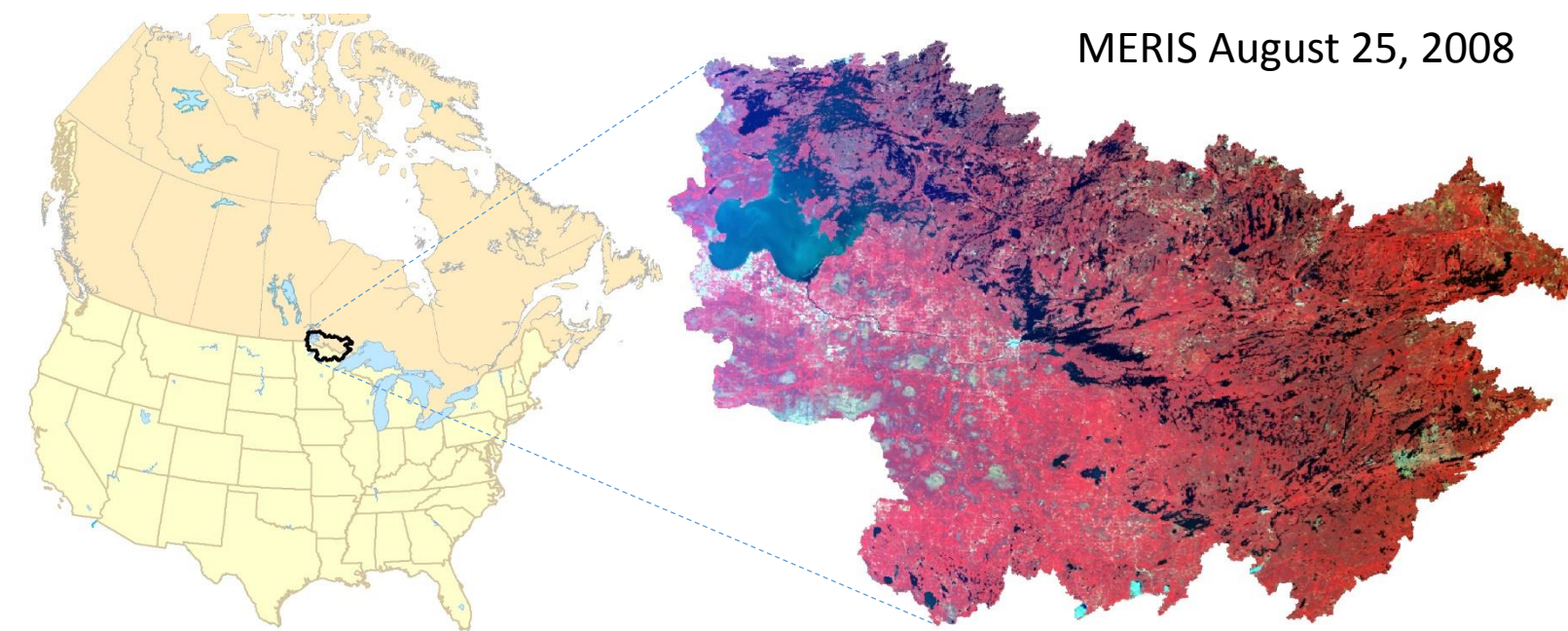


Rationale and Background

With a perceived increase in the frequency and intensity of cyanobacterial algal blooms in Lake of the Woods (LOW), there has been an increased effort to collect information about the nature of algal blooms, nutrient concentrations and sources of nutrients to the LOW. As part of this effort, land cover maps of the LOW Watershed are needed as inputs to hydrology models and analyses of land use and land use change.

Site Location and Size

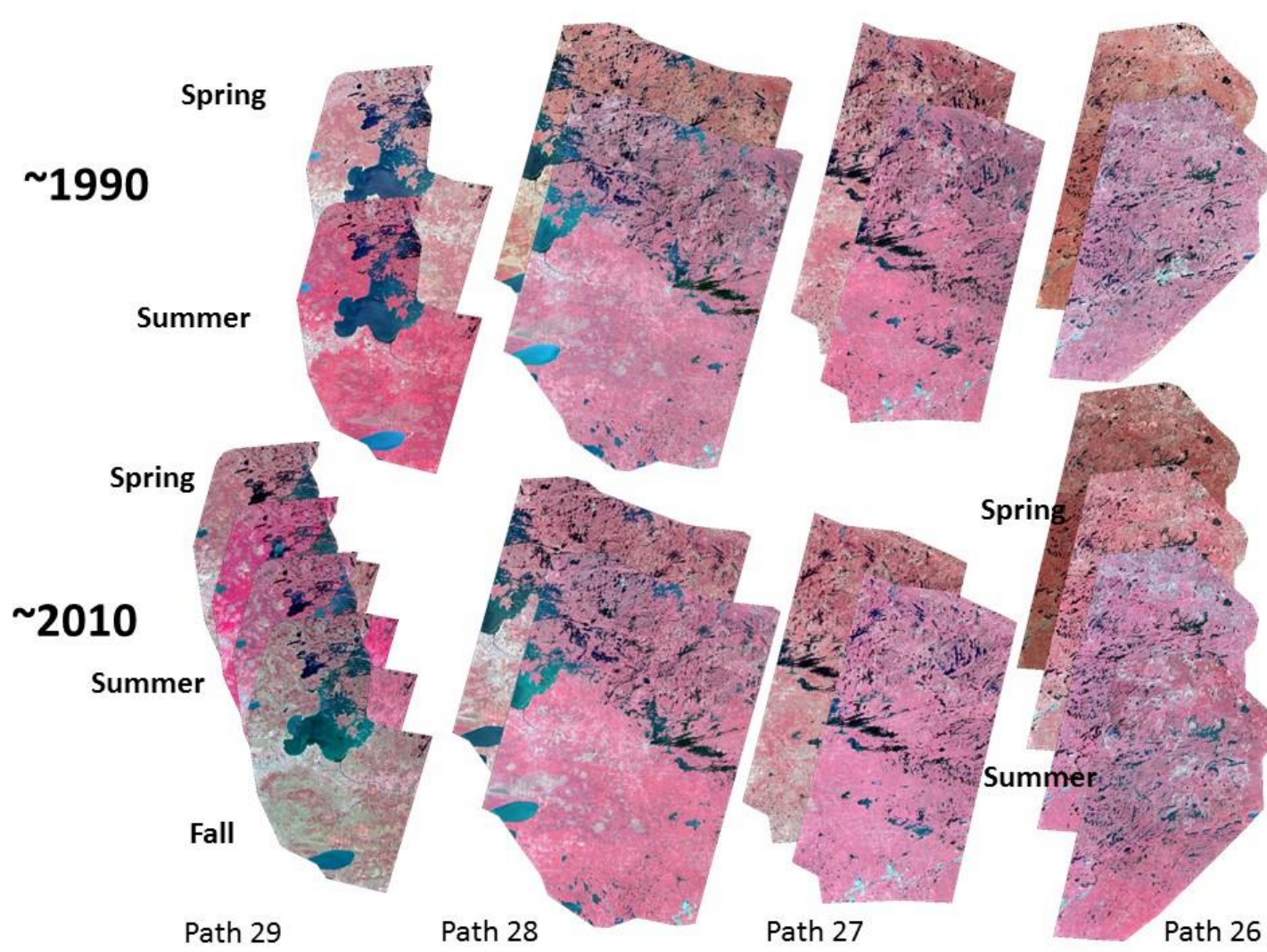
The international Lake of the Woods/Rainy River Basin is an important natural, economic and recreational resource straddling the border between Canada and the United States. The Basin is approximately 400 km (240 mi) east-to-west and 260 km (156 mi) north-to-south. Nearly 60% of its drainage area of about 70,000 km² (27,000 mi²) is located in Ontario, with about 40% in Minnesota and a small portion in Manitoba.



Methods

This project used a combination of multitemporal Landsat imagery, lidar data (Minnesota) and object-based image analysis to cover the entire extend of the Lake of the Woods/Rainy River Basin using a uniform method for the ~1990 and ~2010 time periods so that land cover and changes over that time period can be quantified and used for hydrologic modeling.

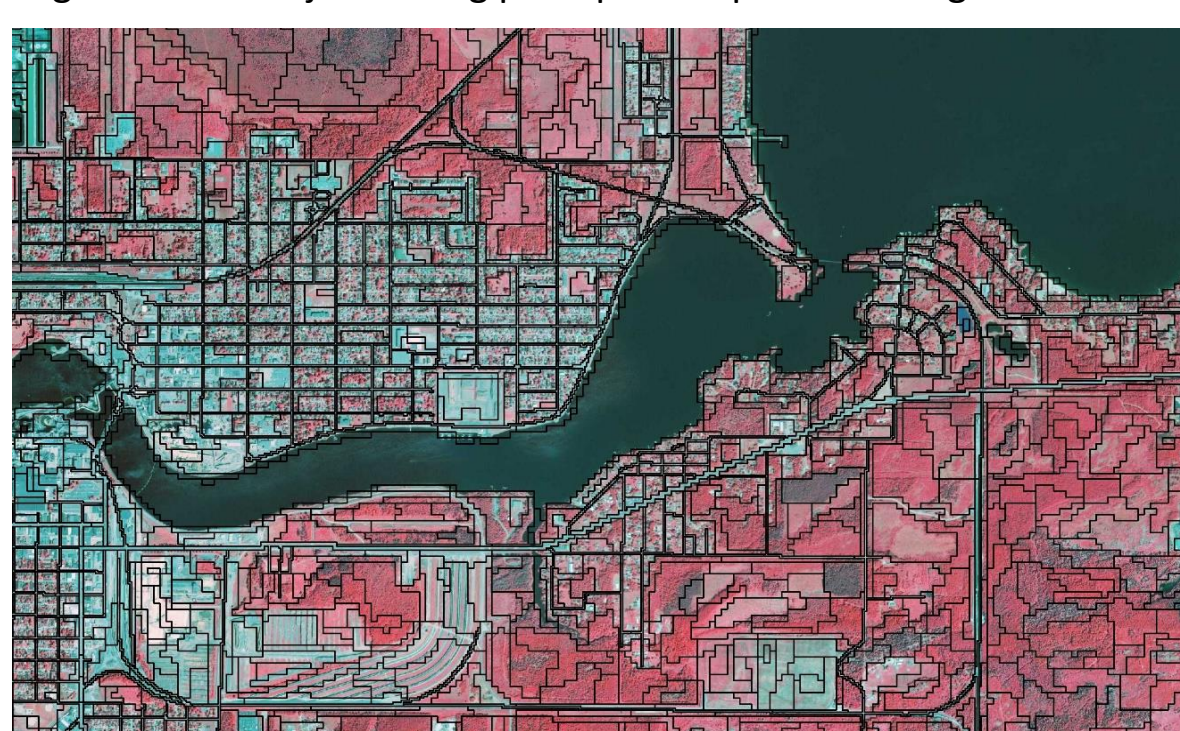
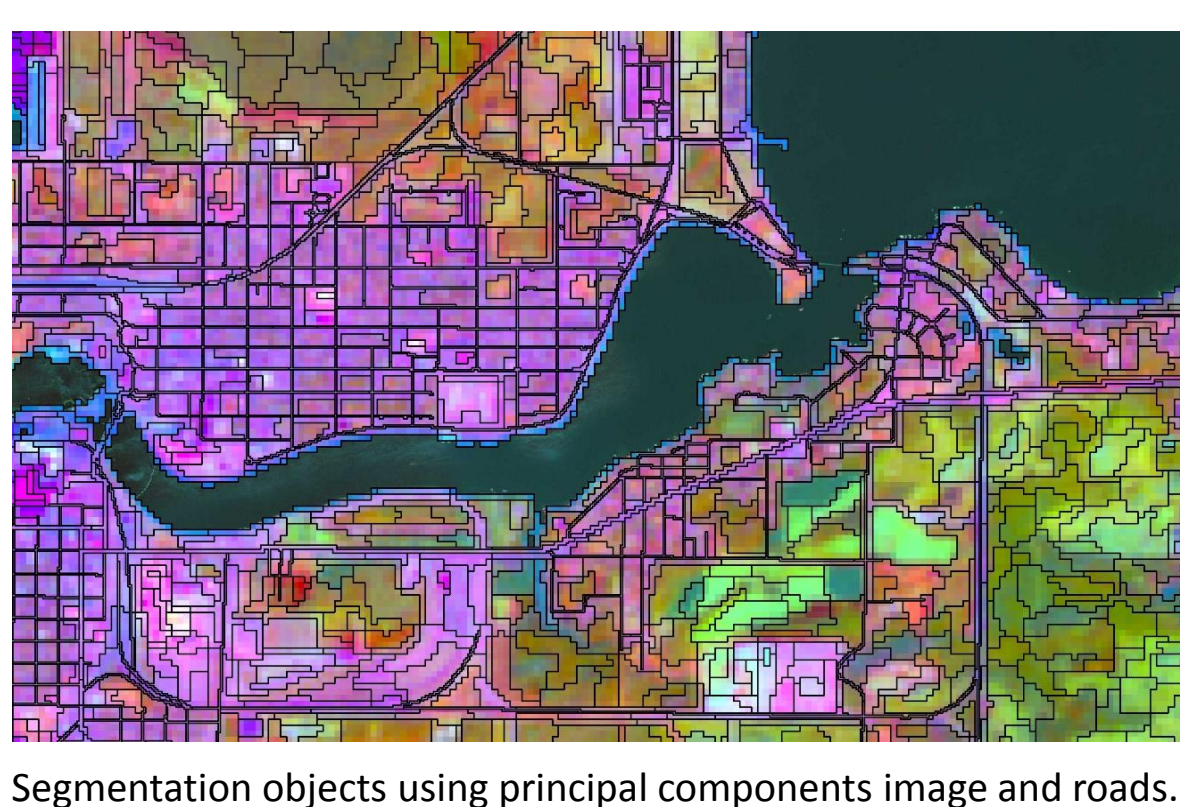
To complete the land cover classification for 1990 and 2010 time periods for the entire 70,000 km² Lake of the Woods/Rainy River Basin 44 Landsat images were utilized. These images included Landsat Thematic Mapper (TM) and Operational Land Imager (OLI) images from different seasons and vegetation development stages to distinguish different kinds of vegetation and other cover.



With multiple dates of imagery per Landsat path, each with seven to ten spectral bands it is useful to compress the images using the principal components. Principal component analysis (PCA) is a mathematical procedure that uses an orthogonal transformation to convert observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. Additional transformations of the Landsat data used were the "tasseled cap" greenness, brightness and wetness and the normalized difference vegetation index (NDVI).

Lidar data acquired provides additional information on height and elevation. Lidar LAS files were acquired from the Minnesota DNR for the tiles within the areas covering the Minnesota portion of the Lake of the Woods/Rainy River Basin. The LAS tiles were used to generate mean and maximum vegetation height rasters at 20-meter spatial resolution. The DNR-provided 1-meter bare earth DEM was also used to create additional lidar-derivative layers at 10-meter spatial resolution, such as Compound Topographic Index (CTI), slope, and dissection. These DEM derived variables are especially useful for wetland identification. More information about the lidar data are available at: <http://www.mngeo.state.mn.us/chouse/elevation/Lidar.html>.

Additional GIS layers used for image segmentation included major roads, other roads and railroads were acquired from the Minnesota Department of Transportation, Ontario Ministry of Natural Resources and Forestry and Manitoba Infrastructure and Transportation. Once the classification was finalized and accuracies were calculated these layers were also overlaid on the maps so that roads narrower than the 30 m Landsat data could be included in the 2010 map. For the 1990 map an edited version of the roads layer was used which excluded roads that were identified as being built since 1990.

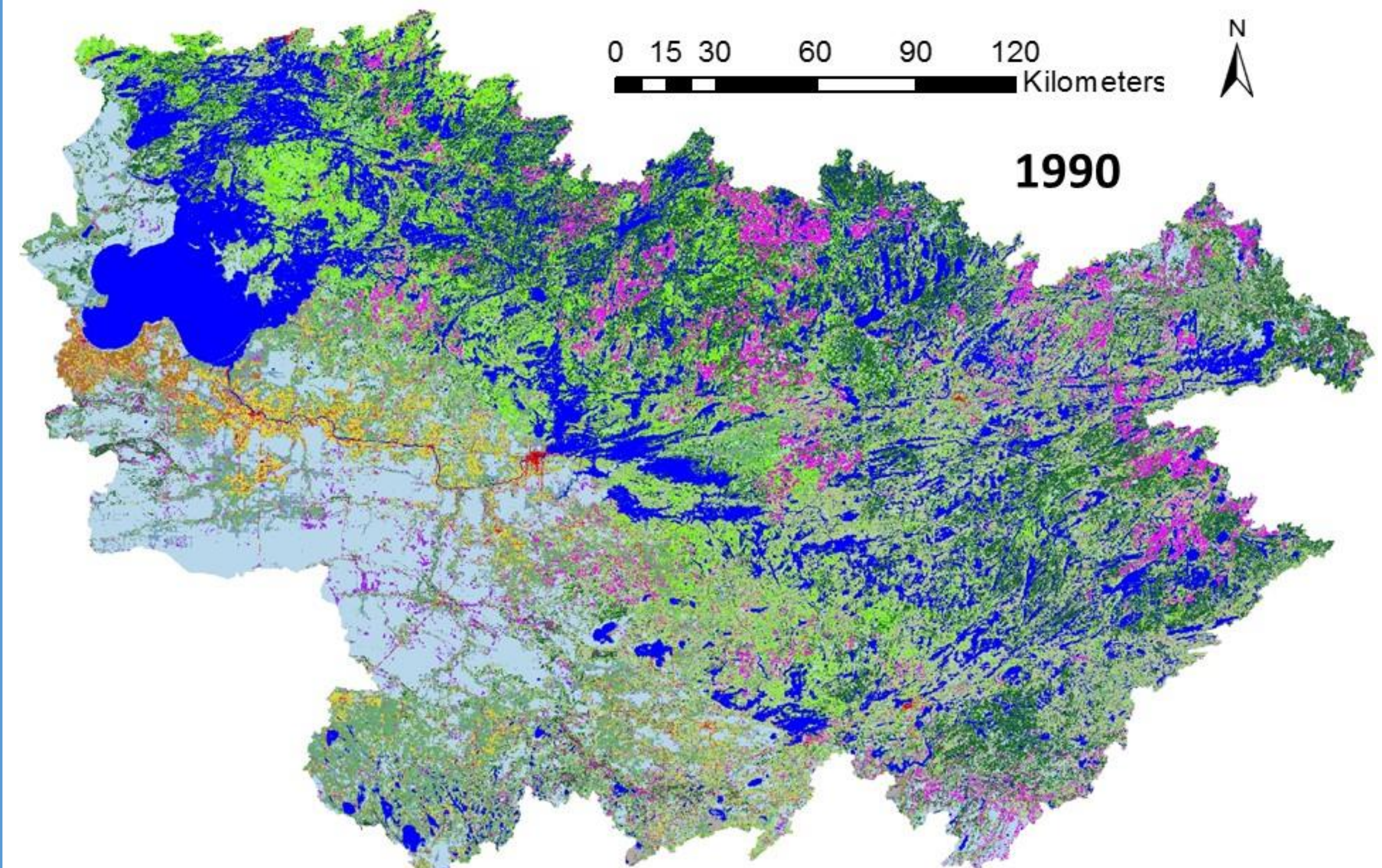


To take advantage of the lidar data that were available in Minnesota, but not Ontario or Manitoba, the Minnesota sections of each Landsat path were classified separately. Therefore to cover the entire Lake of the Woods/Rainy River Basin using the best available data sources eight separate classifications were completed and mosaicked to create the final land cover maps and change maps.

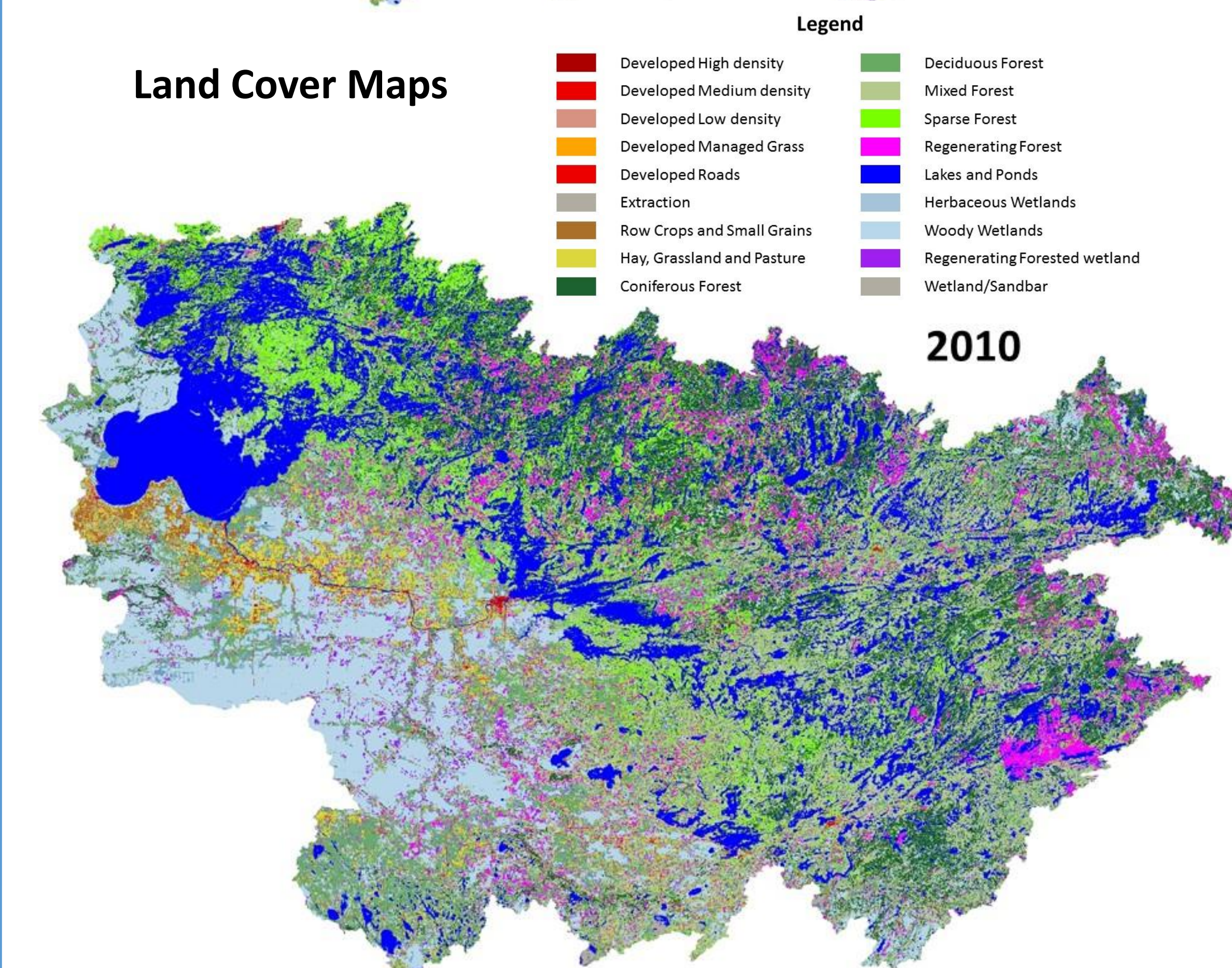
Random forest, a state-of-the-art approach which could handle and take advantage of the large number of features, was used for the classification of the objects. It is an ensemble learning method for classification that operates by constructing multiple decision trees. Each tree is grown on different random subsamples of the training data and during the split selection process by using a subsample of the available features. It allows for the use of a large number of features or variables and identifies the important predictors.

Acknowledgments

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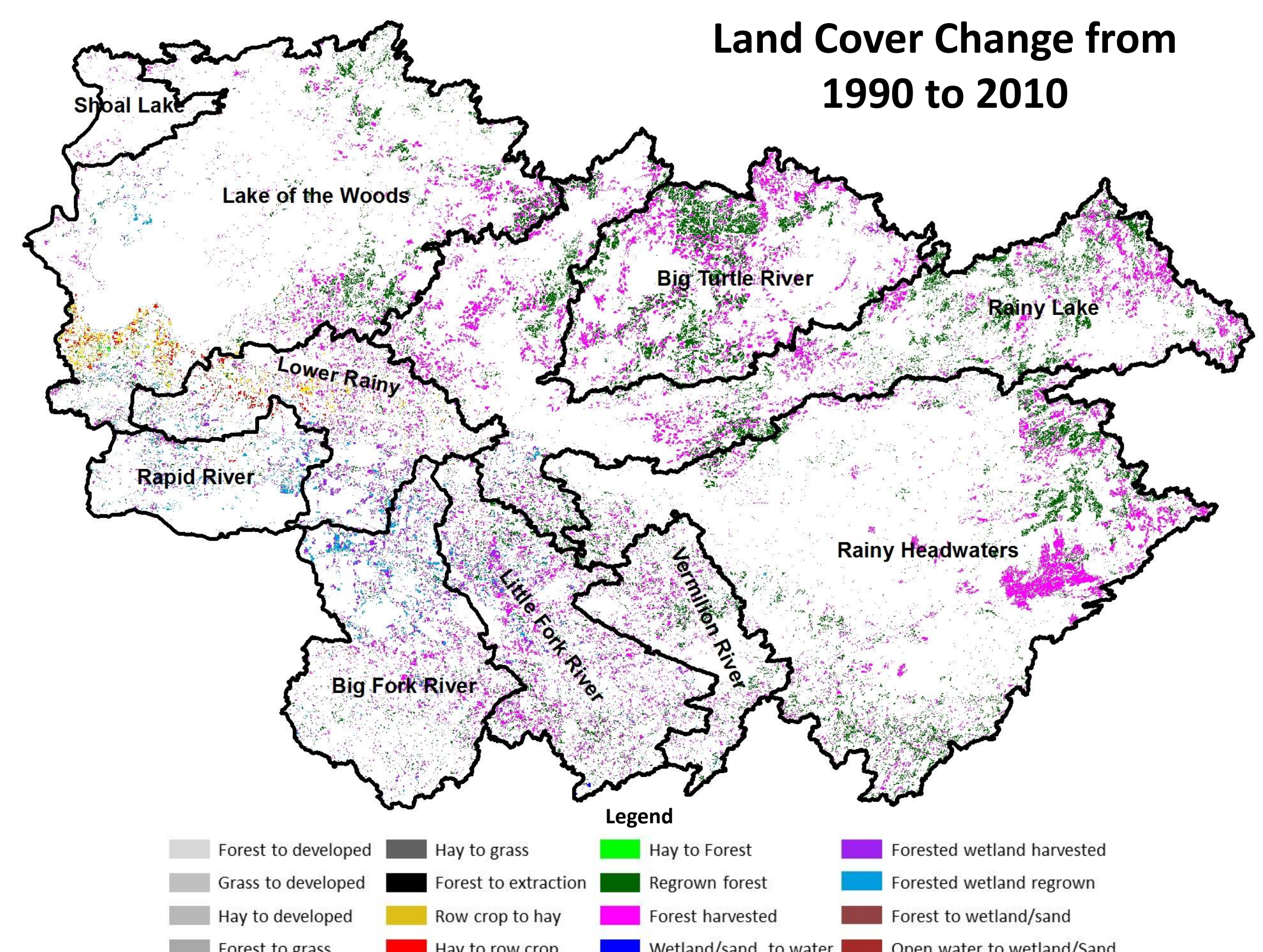


Land Cover Maps



With the finalized maps we tabulated the area and calculated percent of area by class at the sub-basin and total Lake of the Woods/Rainy River Basin for 1990 and 2010. The Lake of the Woods/Rainy River Basin is dominated by forest, wetlands and lakes which comprises 96.3 percent of the basin. Developed areas increased in the basin from 1.30 percent in 1990 to 1.33 percent in 2010. The most obvious changes are due to forest harvesting which is most apparent on the land cover maps or the land change map. There were no changes from 1990 to 2010 for approximately 88% of the basin. While forests that have been harvested move around between the time periods there was also an increase to 5.6% of the basin in 2010 from 4.6% in 1990 that was detected.

Land Cover Change from 1990 to 2010



Accuracy assessment: We evaluated classification accuracy by comparing the classification results to an independent stratified (by class) random reference sample of 6,610 objects (20 percent of the reference data that were withheld from classifier training). The data set has an overall average classification accuracy of 96.4% for level 1 and 92.2% for level 2 land cover classifications. The use of lidar improved the accuracy of the classification; for example in 2010 the overall accuracy for level 1 with lidar data was 98.0% vs. 96.1% without lidar.

Conclusion: A combination of multitemporal Landsat data and lidar data for the Minnesota portion along with object-based image analysis and the random forest classifier enabled accurate level 1 and 2 land cover classifications for the Lake of the Woods/Rainy River Basin for 1990 and 2010. The digital format of the classifications makes it possible to easily include them with other digital maps and data in a GIS for further analysis and modeling. The classification maps and metadata can be viewed or downloaded from a Google Maps based web application at <http://portal.gis.umn.edu>.