2014 Project Abstract
For the Period Ending June 30, 2017

PROJECT TITLE: Update Statewide Land Cover Use Map
PROJECT MANAGER: Joseph Knight
AFFILIATION: University of Minnesota
MAILING ADDRESS: 1530 Cleveland Ave N, 115 Green Hall
CITY/STATE/ZIP: St. Paul, MN 55108
PHONE: 612-625-5354
E-MAIL: jknight@umn.edu
WEBSITE: https://rs.umn.edu
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2014, Chp. 226, Sec. 2, Subd. 05a

APPROPRIATION AMOUNT: $300,000
AMOUNT SPENT: $300,000
AMOUNT REMAINING: $0

Overall Project Outcomes and Results

Conservation and management of Minnesota's natural resources require significant investments of time and money by many state/local agencies and stakeholder groups. The three components of success in such projects (define problem sources, target and track changes) begin with accurate quantification of land cover via Geographic Information System (GIS) or geospatial data. This project updated the statewide land cover data and freely distributed it to all stakeholders. We acquired 130 Landsat satellite images for all of Minnesota for three broad seasons: Spring 2014, Summer 13-14 and Fall 13-14. The Landsat images were preprocessed according to current standards, including cloud correction, mosaicking, and subsetting. We acquired and preprocessed statewide lidar data. Preprocessing included developing Digital Elevation Models, Digital Surface Models, Normalized Digital Surface Models, and Normalized Digital Terrain Models. The imagery and lidar data were classified using an Object-Based Image Analysis (OBIA) approach, wherein the image pixels were aggregated into homogeneous "objects" that have parameters such as spectral values, size, shape, texture, and context. These variables were used in an OBIA classification framework incorporating a Cognition Language ruleset and the Random Forest algorithm to map each object into one of several classes: Forest (and sub-types), Urban (and sub-types), Wetland (and sub-types), Grassland, Extraction, and Agriculture. We produced statewide geospatial land cover/use data for 2013-2014, with higher resolution data for the Twin Cities Metro Area, Duluth, and Rochester. The classified maps have very high accuracy.

Project Results Use and Dissemination

All of the project data have been posted to the Minnesota Geospatial Commons (https://gisdata.mn.gov/dataset/base-landcover-minnesota), the Data Repository for the University of Minnesota (https://conservancy.umn.edu/handle/11299/181555), and the UMN Remote Sensing and Geospatial Analysis Laboratory (https://rs.umn.edu/datalayers) websites. A full project report has been provided separately. We have announced the availability of the data using several methods: via email, in person, in presentations at the MN GIS/LIS conference, and other communications. We regularly receive positive comments from users of the data. Scientific journal articles are in preparation.

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2014 Work Plan

Date of Report: November 30, 2016

Date of Next Status Update Report: November 30, 2016

Date of Work Plan Approval: June 4, 2014

Project Completion Date: November 30, 2016

Does this submission include an amendment request? No

PROJECT TITLE: Update Statewide Land Cover Use Map

Project Manager: Joseph Knight

Organization: University of Minnesota

Mailing Address: 1530 Cleveland Ave N, 115 Green Hall

City/State/Zip Code: Saint Paul, MN 55108

Telephone Number: (612) 625-5354

Email Address: jknight@umn.edu

Web Address: http://rsl.gis.umn.edu/

Location: Statewide

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$300,000**
	Amount Spent:	**$300,000**
	Balance:	**$0**

Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 05a

Appropriation Language:
$300,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to update Minnesota's land cover data at moderate spatial resolution statewide and at high resolution for selected areas, distribute products, and provide training. This appropriation is available until June 30, 2017, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Update Statewide Land Cover Use Map

II. PROJECT STATEMENT: Conservation and management of Minnesota's natural resources require significant investments of time and money by many state/local agencies and stakeholder groups. For example, in FY 2013, Clean Water Funding for restoration and protection watershed projects is over $95 million.

The three components of success in such projects (define problem sources, target and track changes) begin with accurate quantification of land cover via Geographic Information System (GIS) or geospatial data. Land cover data shows the composition of a landscape, such as forest, water, impervious surface, agriculture, etc. Examples of uses for land cover data in Minnesota are:

1. The Metropolitan Council uses land cover data to plan many critical infrastructure projects. Updated land cover data is required to base infrastructure decisions on current information.
2. The Pollution Control Agency (PCA) uses land cover data as input to models describing water flow over the landscape (among other uses). These models are important for projecting where and how water will flow in response to rainfall events of various strengths. Correct land cover data is required because different cover types influence the flow of water in different ways (for example, impervious versus grassy areas). Updated land cover data is required so that limited state resources can be used in the most effective ways.
3. The MN Department of Natural Resources (DNR) Community Forestry group would use updated land cover data to estimate urban tree canopy (UTC) cover for various areas of interest. Information about current UTC is important for estimating the effects of temperature regulation, shading, water flow, and leaf deposition. As UTC changes due to the effects of climate change and pests like the Emerald Ash Borer, models based on older land cover data will increasingly produce incorrect results. Therefore, updated land cover data is required for optimal decision making.

However, the existing statewide land cover data is badly out-of-date (2000) and does not include the effects of the boom growth period, changes in agricultural production, or changing forests. Alternative datasets (e.g. the National Land Cover Data) are inadequate for many of Minnesota's needs. Thus, this project is driven directly by the needs of local, county, state agencies and other stakeholders.

This project will update the statewide land cover data and freely distribute it to all stakeholders. We will produce statewide geospatial data for 2013-2014, with higher resolution data for selected parts of the state. Statewide 1/4-acre (30-meter) spatial resolution products will allow us to identify current land uses as well as track changes from 2000 to today that are applicable to diverse conservation goals. Higher resolution 1-2 meter geospatial data products will be developed for selected urban areas. We are currently planning high resolution mapping for the Twin Cities Metropolitan Area, Duluth, and Rochester. Depending on our progress with the complexities of mapping at such high resolutions, we may modify the list to remove or add areas (if funding and time allow). Any additional areas would be those deemed especially sensitive that would benefit from higher resolution. The University of Minnesota will distribute all of the data and statistics in easily displayed GIS-compatible format through existing information websites including the DNR's Data Deli and MnGeo and the University of Minnesota's (UMN) Remote Sensing website (www.land.umn.edu) as well as provide website tutorials. Three data use workshops will be conducted for project stakeholders at appropriate locations.

III. PROJECT STATUS UPDATES:

Project Status as of *December, 2014*: The project is on schedule and on budget. We have acquired 130 Landsat satellite images for all of Minnesota for three broad seasons: Spring 2014, Summer 13-14 and Fall 13-14. The Landsat images were preprocessed according to current standards, including cloud correction, mosaicking, and subsetting. We have acquired from MNGeo and preprocessed statewide lidar data. Preprocessing included developing Digital Elevation Models, Digital Surface Models, Normalized Digital Surface Models, and Normalized

Digital Terrain Models. We have investigated the commercial satellite imagery archive and found that there is sufficient imagery to allow for high-resolution classification of the areas identified in the proposal. We provide more detailed updates in the task descriptions below.

Project Status as of *June, 2015*: The project is on schedule and on budget. After acquiring a processing the large amount of Landsat imagery and lidar data described in the previous project status update, we have moved forward to the classification step. This step is described in much more detail below but in summary, the input data were partitioned using state-of-the-art techniques (Object-Based Image Analysis and Random Forest) into the land cover/use classes of interest. The final classification statistical accuracy is yet to be measured (this comes at a later deliverable date), but indications are that it will be very good.

Project Status as of *December, 2015*: The project is on schedule and on budget. The statewide classification is complete, and has high accuracy (described below). We are proceeding with classifying the three high-resolution areas. All of the imagery has been processed and mosaicked, and classification trials are ongoing. We are preparing for the outreach and dissemination portions of the project, to be completed before the June 30, 2016 end date.

Amendment Request on *May 19, 2016*: We request additional time to complete the outreach portion of Activity 3. While we expect to have all of the map products complete, we would like to spend more time publicizing the results and helping stakeholders obtain and use the data.

Amendment approved by LCCMR 5-24-2016

Project Status as of *June, 2016*: The project is on budget and is expected to meet the amended schedule. The statewide classification is complete and has high accuracy (see below). The three high-resolution classifications are complete and also have high accuracy (see below). We have prepared the classifications for dissemination. The remaining tasks are user outreach and dissemination. We expect to complete the project by the November 30 end date and deliver the final report shortly thereafter.

Overall Project Outcomes and Results: The project is complete. As noted above, the statewide and three high-resolution classifications are complete and have been made available for download on the Minnesota Geospatial Commons, the Data Repository for the University of Minnesota, and the UMN Remote Sensing and Geospatial Analysis Laboratory websites. We have announced the availability of the data using several methods: via email, in person, in presentations at the MN GIS/LIS conference, and other communications. We are preparing a final project report.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Update the statewide land cover map for 2013/2014
Description: The State's land cover data will be updated consistent with existing classifications. We anticipate that the main classes will be: cropland, forest, wetland, grassland, shrubland, water, and urban/developed + impervious surfaces. The classes will be subdivided into more thematic detail where possible. We will search the Landsat imagery archive for data appropriate for an updated Minnesota classification. We hope to be able to use only images from the newly-launched Landsat 8 satellite, as the data quality is better than previous versions of the satellite. However, cloud or haze cover may make complete coverage for the state impossible. In that case, we will use Landsat 5 or 7 images where necessary. The mapping will be done using a combination of Landsat optical imagery and the statewide lidar dataset in an object-based image analysis (OBIA) environment. Unlike previously used pixel-based classification systems, using OBIA allows for a more accurate and aesthetically pleasing map.

Summary Budget Information for Activity 1: **ENRTF Budget: $ 91,370**
Amount Spent: $ 91,370
Balance: $ 0

Activity Completion Date: December, 2015

Outcome	**Completion Date**	**Budget**
1. *Acquire satellite data and process for 54 million acres*	January, 2015	$ 10,000
2. *Generate land cover classification datasets for Minnesota*	June, 2015	$ 70,000
3. *Map municipality/MCD impervious surface area for 2,367 MCDs*	December, 2015	$ 11,370

Activity Status as of *December, 2014*: We have acquired and processed all of the satellite data for Outcome #1. We have begun working on draft classifications for pilot areas. This task is on schedule and on budget. 130 Landsat 8 satellites images for Minnesota were acquired for Spring 2014; Summer 2013-14; and Fall 2013-14. A majority of the Landsat satellite imagery was cloud-free, but minor cloud correction was required for some images. The 30-meter Landsat 8 data were rectified and reprojected to NAD 1983 datum, Universal Transverse Mercator (UTM) map projection, Zone 15. Each image was layer-stacked (12 bands stacked), mosaicked and clipped to the MnDNR ecoregion boundaries (7 ecoregions) with a buffer area of 0.5 miles for future overlap. In addition, each Landsat image was resampled to 15 m spatial resolution using an Imagine (img) format.

Landsat imagery was collected as follows:
- Spring 2014: 15 images collected: May 10, Apr 17, May 28 , Apr 10, May 30, May 23
- Summer 2013: 30 images collected: Jul 12, Aug 31, Aug 22, Aug 20
- Summer 2014: 25 images collected: Jun 8, Jun 4, Jun 29, Jul 17, July 22, Jul 31
- Fall 2013: 30 images collected: Oct 9, Sept 23, Oct 16, Oct 27
- Fall 2014: 30 images collected: Oct 21, Sep 16, Sep 5, Sep 28

Lidar data status:
Lidar LAS files were acquired from MNGeo for Minnesota. The LAS files were used to create a 15 m Digital Elevation Model (DEM), Digital Surface Model (DSM), Digital Terrain Model (DTM), Compound Topographic Index (CTI), Slope, and building footprints.

Activity Status as of *June, 2015*:
The imagery and lidar data were classified using an Object-Based Image Analysis (OBIA) approach, wherein the image pixels were aggregated into homogeneous "objects" that have parameters such as spectral values, size, shape, texture, and context. These variables were used in an OBIA classification framework incorporating a Cognition Language ruleset and the Random Forest algorithm to map each object into one of several classes: Forest (and sub-types), Urban (and impervious surface percentages), Wetland (and sub-types), Grassland (and sub-types), and Agriculture (and sub-types). The Minnesota-wide lidar dataset was essential to the good performance this classification process exhibited. Without lidar, we would have struggled to discriminate some of the classes and sub-types.

The next steps in the project are to prepare the high-resolution classification and to create the map deliverables. These steps will occur within the next reporting period.

Activity Status as of *December, 2015*: This activity is complete. The only addition since the last reporting period is that the validation has been completed. The statewide classification has an accuracy of approximately 96%, which is exceptionally good.

Activity Status as of *June, 2016*: This activity is complete. Please see update above.

Final Report Summary: The statewide classification is complete and available for download as described above.

ACTIVITY 2: Generate high resolution land cover/use products for selected Greater Minnesota areas and Twin Cities Metropolitan Area (TCMA)
Description: We will acquire, process and combine high resolution satellite data with existing lidar data for improved land cover classification (2-4 meters). We are currently planning high resolution mapping for the Twin Cities Metropolitan Area, Duluth, and Rochester. Depending on our progress with the complexities of mapping at such high resolutions, we may modify the list to remove or add areas (if funding and time allow). Any additional areas would be those deemed especially sensitive that would benefit from higher resolution. We anticipate having access to sufficient high resolution imagery to perform this mapping. The imagery, which comes from the DigitalGlobe archive, will be acquired via an agreement with NASA (National Aeronautics and Space Administration) and the National Geospatial-Intelligence Agency (NGA) and will be free of charge. An OBIA system, as described above, will be used to classify the

Summary Budget Information for Activity 2: **ENRTF Budget: $ 86,600**
Amount Spent: $ 86,600
Balance: $ 0

Activity Completion Date: December, 2015

Outcome	**Completion Date**	**Budget**
1. *1. Acquire state-of-the-art satellite data and integrate with existing lidar data covering selected TCMA and Greater MN areas*	November, 2014	$ 10,000
2. *Generate land cover products for selected areas*	August, 2015	$ 60,000
3. *Define impervious surfaces for selected areas*	December, 2015	$ 16,600

Activity Status as of *December, 2014*: We have the necessary satellite and lidar imagery in hand. For the Twin cities there are approximately 510 images, mostly from WorldView, Quick Bird and IKONOS from 2001 – 2013. For Duluth there are approximately 215 images from WorldView, Quick Bird and IKONOS and GEOEYE from 2005 – 2013. For Rochester there are approximately 88 images from WorldView, IKONOS and GEOEYE from 2007 – 2013. Minor preprocessing is still required. This task is on schedule and on budget.

Activity Status as of *June, 2015*: We have spent most of our recent time on the statewide classification, so this task has not progressed significantly since the last report. We have the needed data in-hand and expect to prepare the high-resolution classifications by the next reporting period. This task is on schedule and on budget.

Activity Status as of *December, 2015*: After encountering problems with using the satellite imagery mentioned in a previous update, we made a change to our plan and are now using National Agricultural Imagery Program (NAIP) data as the base image dataset for classification (along with lidar) for the TCMA and Greater MN areas. This change puts this Activity slightly behind schedule, but we are confident that the project as a whole will be completed on time.

Activity Status as of *June, 2016*: This activity is complete. The imagery and lidar data were classified using an Object-Based Image Analysis (OBIA) approach, wherein the image pixels were aggregated into homogeneous "objects" that have parameters such as spectral values, size, shape, texture, and context. These variables were used in an OBIA classification framework incorporating a Cognition Language ruleset and the Random Forest algorithm to map each object into one of several classes: Forest (and sub-types), Urban (and sub-types), Wetland (and sub-types), Grassland, Extraction, and Agriculture. The Minnesota-wide lidar dataset was essential to the good performance this classification process exhibited. Without lidar, we would have struggled to discriminate some of the classes and sub-types.

The high-resolution classifications have Level 1 accuracies of 85% or better, depending on which of the three areas are considered (the TCMA, Duluth, or Rochester). Accuracies meeting or exceeding an 85% threshold are considered in the geospatial field to be excellent.

Final Report Summary: The three high-resolution classifications are complete and available for download as described above.

ACTIVITY 3: Distribute updated land cover and train users
Description: The project will freely distribute data and statistics of seven standard land covers and percent impervious surface area, in an ArcGIS database and MapServer application (or similar technology) for both metro and statewide areas for updating of watershed computer modeling efforts. MapServer enables display and analysis of spatial data over the Internet. Products and statistics summarizing the classifications by city, township, county, ecoregion, watershed and catchment may be generated and added to the online database available at land.umn.edu, as funds and time allow. Three training sessions will be conducted by the University of Minnesota using existing Board of Water and Soil Resources (BWSR), Minnesota Association of Watershed Districts (MAWD), and Soil and Water Conservation District (SWCD) venues for cities, counties and professional engineering services.

Summary Budget Information for Activity 3: **ENRTF Budget: $ 122,030**
Amount Spent: $ 122,030
Balance: $ 0

Activity Completion Date: November, 2016

Outcome	**Completion Date**	**Budget**
1. *Convert into GIS datasets and web-based maps, along with area statistics by county, city/township, ecoregion, watershed and catchment for 54 million acres*	December, 2015	$ 102,030
2. *User training and distribution of map and GIS products on UM website*	November, 2016	$20,000

Activity Status as of *December, 2014*: We have not yet begun work on this Activity because it is dependent on results from the previous two Activities.

Activity Status as of *June, 2015*: We have not yet begun work on this Activity because it is dependent on results from the previous two Activities.

Activity Status as of *December, 2015*: We are preparing to work on this Activity but cannot make significant progress because it is dependent on results from the previous two Activities.

Amendment request on *May 19, 2016*: We request additional time to complete the outreach portion of Activity 3. While we expect to have all of the map products complete, we would like to spend more time publicizing the results to make sure all stakeholders are aware of these new maps.

Amendment approved by LCCMR 5-24-2016

Activity Status as of *June, 2016*: We have converted the statewide and high-resolution classifications to GIS format and generated summary statistics. We are proceeding with user training, which will occur at the MN GIS/LIS annual conference and other venues.

Final Report Summary: All of the project data have been posted to the Minnesota Geospatial Commons, the Data Repository for the University of Minnesota, and the UMN Remote Sensing and Geospatial Analysis Laboratory websites. We have announced the availability of the data using several methods: via email, in person, in presentations at the MN GIS/LIS conference, and other communications.

V. DISSEMINATION:

Description: Dissemination will be largely as described in Activity 3, above. We will ensure that awareness of the dataset among stakeholders is as great as possible, through training workshops, email announcements, social media, and other appropriate outreach efforts. All data products, reports, and methods will be available at no cost via the land.umn.edu website and other outlets such as the DNR Data Deli.

Status as of *December, 2014*: We have not yet begun work on this Activity because it is dependent on results from the previous two Activities.

Status as of June, 2015: We have not yet begun work on this Activity because it is dependent on results from the previous two Activities.

Status as of *December, 2015***:** We are preparing to work on this Activity but cannot make significant progress because it is dependent on results from the previous two Activities.

Amendment request on *May 19, 2016*: We request additional time to complete the dissemination portion of Activity 3. While we expect to have all of the map products complete, we would like to spend more time helping stakeholders obtain and use the data.

Amendment approved by LCCMR 5-24-2016

Status as of *June, 2016:* We have prepared the statewide and high-resolution classifications for publication. We plan to disseminate the data products on the UMN Remote Sensing and Geospatial Analysis Laboratory (RSGAL) website, the Data Repository for U of M (DRUM) website, and the Minnesota Geospatial Commons. These three distribution points will ensure the widest possible availability for stakeholders.

Final Report Summary: The data have been posted to the Minnesota Geospatial Commons, the Data Repository for the University of Minnesota, and the UMN Remote Sensing and Geospatial Analysis Laboratory websites. We have announced the availability of the data using several methods: via email, in person, in presentations at the MN GIS/LIS conference, and other communications.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Explanation
Personnel:	$ 295,230	Project supervisor (20% FTE, 2 years), research associate (100% FTE, 2 years), graduate research assistant (50% FTE, 2 years), graduate research assistant (25% FTE, 2 years) and IT specialist (20% FTE, 2 years). Project work, dissemination, and supervision
Travel Expenses in MN:	$ 4,770	Mileage, lodging, and meals for UMN project personnel to travel to/from field validation sites throughout Minnesota. Estimate of 3,000 miles @ $0.56 per mile plus loding and food for 25 days at $123 per day
TOTAL ENRTF BUDGET:	**$ 300,000**	

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $5,000: N/A

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 4.3

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: N/A

B. Other Funds: N/A

VII. PROJECT STRATEGY:

A. Project Partners: Marvin Bauer (UMN), stakeholders (e.g. state agencies, SWCDs, etc.) will be involved through periodic advisory meetings.

B. Project Impact and Long-term Strategy: This project is the latest in a series of efforts to describe Minnesota's changing land cover. The data products developed will follow the most recent mapping, done in 2000. Monitoring Minnesota's land cover is critical for many reasons, as described in the Project Statement above. Our long term strategy will involve attempting to obtain stakeholder funding to perform future mapping. Maintenance of the data distribution tools is a continuing function of the Remote Sensing and Geospatial Analysis, which will continue regardless of funding for future mapping.

C. Spending History: N/A

VIII. ACQUISITION/RESTORATION LIST: N/A

IX. VISUAL ELEMENT or MAP(S): See attached maps

X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET: N/A

XI. RESEARCH ADDENDUM: N/A

XII. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted no later than December 2014, June 2015, and June 2016. A final report and associated products will be submitted by December 31, 2016.

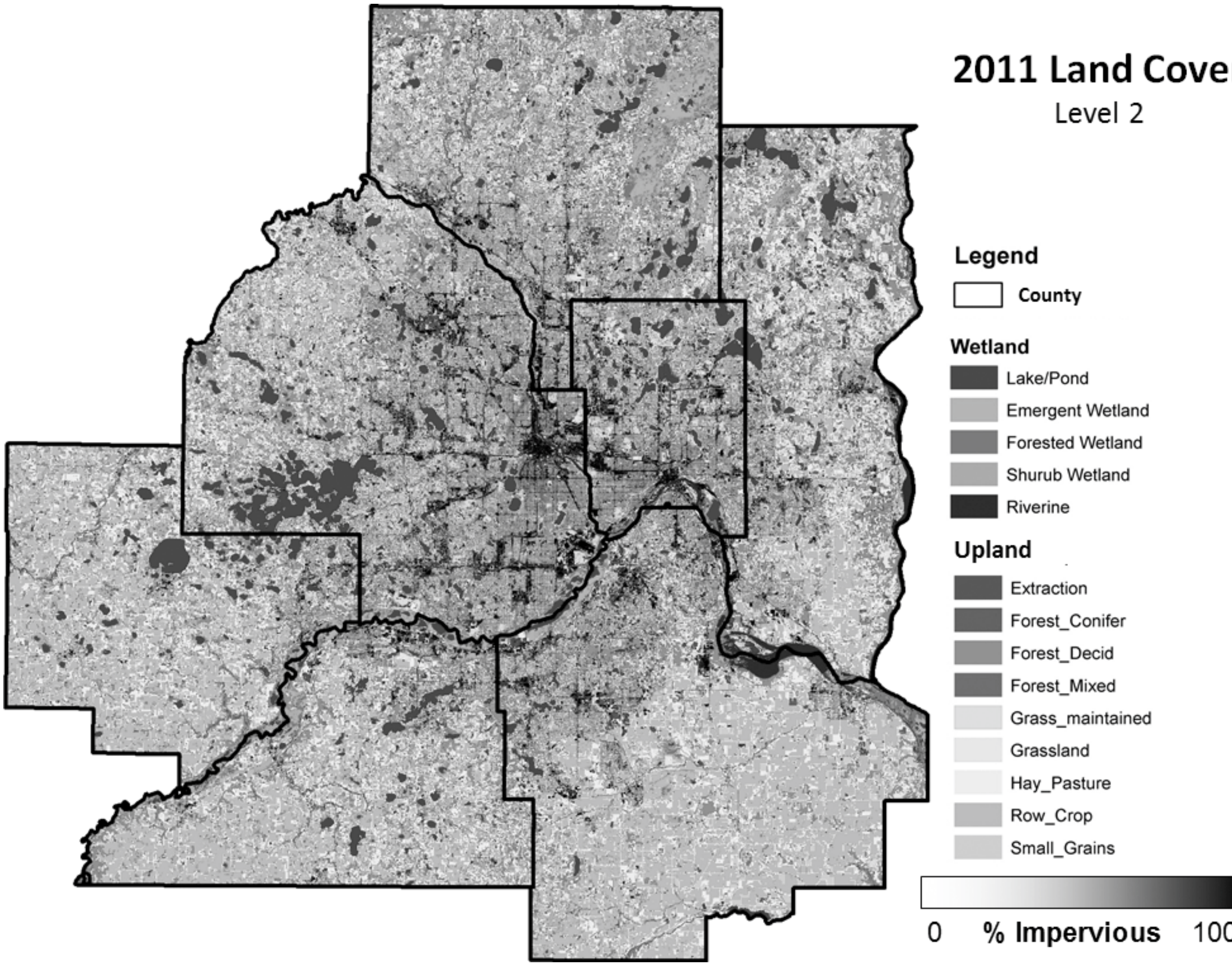

Figure 1: Land cover for the Twin Cities Metropolitan Area, 2011

Environment and Natural Resources Trust Fund
M.L. 2014 Project Budget

Project Title: *Update Statewide Land Cover Use Map*
Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 05a
Project Manager: *Joseph F. Knight*
Organization: *University of Minnesota*
M.L. 2014 ENRTF Appropriation: $ *300,000*
Project Length and Completion Date: *2 Years 5 Months, November 30, 2016*
Date of Report: November 30, 2016

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	***Update the statewide land cover map***			***Generate high resolution land cover maps***			***Distribute land cover and train users***				
Personnel (Wages and Benefits)	$86,600	$86,600	$0	$86,600	$86,600	$0	$122,030	$122,030	$0	$295,230	$0
Lian Rampi, Reseach Associate: $47,000 (33.8% fringe); 100% FTE for 2 years											
Graduate Research Assistant: $18,500 (74% fringe); 50% FTE for 2 years											
Graduate Research Assistant: $18,500 (74% fringe); 25% FTE for 2 years											
Trent Erickson, IT Specialist: $20,430 (33.8% fringe); 20% FTE for 2 years											
Joe Knight, Project Manager: $83,500 (33.8% fringe); 20% FTW for two years											
Travel expenses in Minnesota Mileage, lodging, and meals for UMN project personnel to travel to/from field validation sites throughout Minnesota. Estimate of 3,000 miles @ $0.56 per mile plus loding and food for 25 days at $123 per day	$4,770	$4,770	$0	$0	$0	$0	$0	$0	$0	$4,770	$4,770
COLUMN TOTAL	**$91,370**	**$91,370**	**$0**	**$86,600**	**$86,600**	**$0**	**$122,030**	**$122,030**	**$0**	**$300,000**	**$0**

Minnesota Statewide Land Cover Update and Urban High Resolution Land Cover Classifications

January, 2017

Principal Investigator: Joseph Knight, Associate Professor
Remote Sensing and Geospatial Analysis Lab, University of Minnesota
1530 Cleveland Avenue North
St. Paul, MN 55108
Phone: 612-625-5354
Fax: 612-625-5212
Email: jknight@umn.edu

Authors: Joseph Knight, Lian Rampi, and Trevor Host

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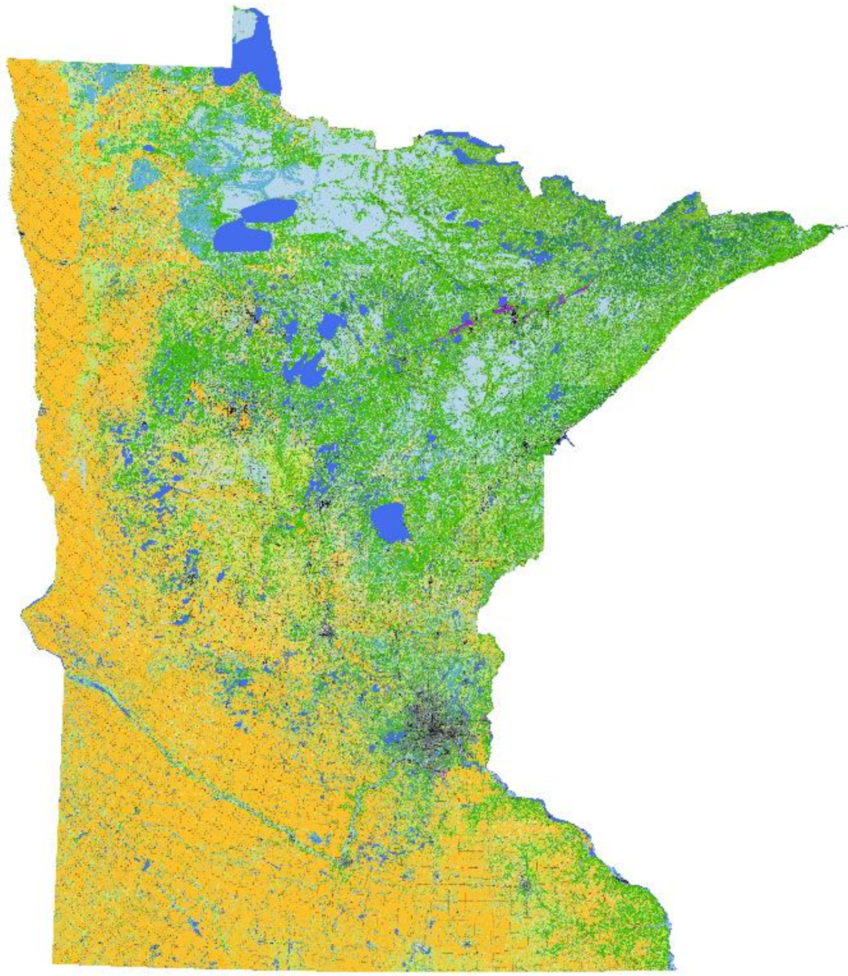
Minnesota statewide and urban high resolution land cover classification



Rationale and Background

Land cover information plays an important role as a basic inventory of land resources for local, regional, and state land use planning. This is particularly significant for metropolitan areas such as the Twin Cities of Minneapolis-St. Paul, Minnesota which include seven counties and more than 100 civil government units.

Remote sensing data have a long history of producing land cover maps from aerial photography and satellite imagery. Nevertheless, the cost of aerial photography acquisition and interpretation and digitization of cover types is prohibitively expensive for large geographic areas. Aerial photography, which was accessible before the launch of the first Landsat platform in 1972, still remains as a valuable data for analyzing historical and current land cover changes (Foody, 2002; Thomson et al., 2007).

Alternatively, acquisition of satellite data has grown effectively at all scales. Satellite data has numerous advantages: (1) the synoptic view of the sensor offers coverage of large geographic areas (e.g. an individual image covers 100 x 100 miles), (2) the digital form of the data provides itself to more efficient analysis, (3) land cover maps are compatible with geographic information systems, eliminating the need to digitize interpreted information, and (4) land cover maps can be created at significant cheaper cost than other methods (albeit at 30-meter spatial resolution).

Several research studies at the University of Minnesota have demonstrated the potential for classifying land cover with different satellite data including medium spatial resolution data such as Landsat and high spatial resolution such as NAIP data (Yuan, et al., 2005a and 2005b; Bauer, et al., 2007; Rampi, et al., 2014).

Two datasets were produced: This is a 15-meter raster dataset of a land cover and impervious surface classification of the state of Minnesota to provide an update to 2013, level two classification. The classification was created using a combination of multitemporal Landsat 8 data and Lidar data with Object-Based Image Analysis (OBIA). By using objects instead of pixels, we were able to utilize multispectral data along with spatial and contextual information of objects such as shape, size, texture and Lidar-derived metrics to distinguish different land cover types (Platt and Rapoza 2008; Blaschke, T. 2010). While OBIA has become the standard procedure for classification of high resolution imagery, we found that it works equally well with Landsat imagery. For the objects classified as urban or developed, a regression model relating the Landsat greenness variable to percent impervious was developed to estimate and map the percent impervious surface area at the pixel level.

Methods

1. Landsat Data Acquisition and Processing

A Mosaic of Landsat 8 Images was completed using the ERDAS software and consisted of several Landsat multispectral images for the following dates:

- June 24, 2013
- July 3,7,21,23,28, 2013
- August 22, 2013
- September 16,23,25,30, 2013
- October 7,9,11,16,18,27, 2013
- May 26,28,30, 2014
- June 4,6,8,13, 2014

The spatial resolution of this data is 30-meters and 2 bands (Thermal Infrared Sensor) 10-11, collected at 100 meters but resampled to 30 meters to match the multispectral bands. All multispectral bands were resampled to 15 meters using the panchromatic 15 m band. The RMS error of the Landsat data was less than 7.5 meters (0.25 Landsat pixel). Landsat images were georectified to UTM Zone 15N. Further information about Landsat is available at http://landsat.usgs.gov/.

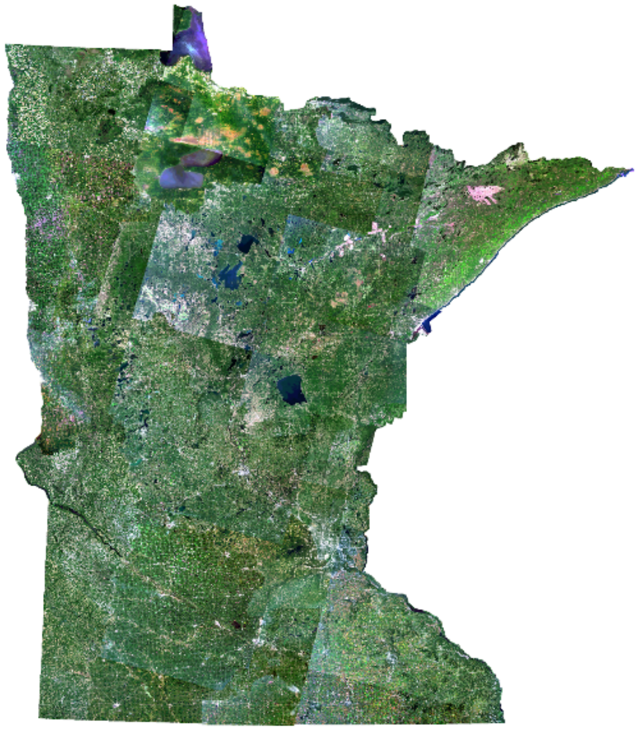


Figure 1. Landsat 8 Mosaic Summer 13-14 (3-band false color composites).

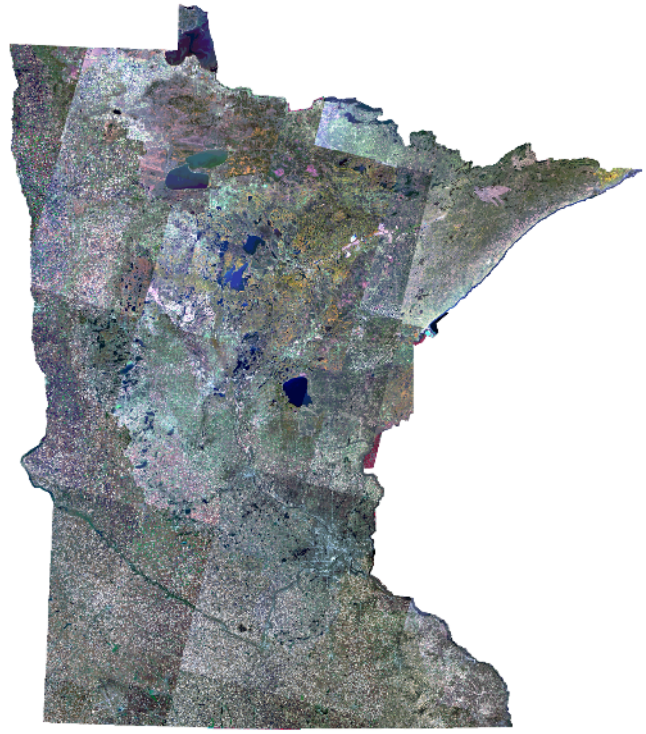


Figure 2. Landsat 8 Mosaic Fall 13-14 (3-band false color composites).

The following spectral indices were derived from the summer and fall Landsat data: Normalized Difference Vegetation Index (NDVI) see figures 3 and 5, Transformed Normalized Difference Vegetation Index (TNDVI), Ratio Vegetation Index (RVI: Red/NIR), Infrared divided by Red (NIR/Red), and Modified Soil Adjusted Vegetation Index 2 (MSAVI2).

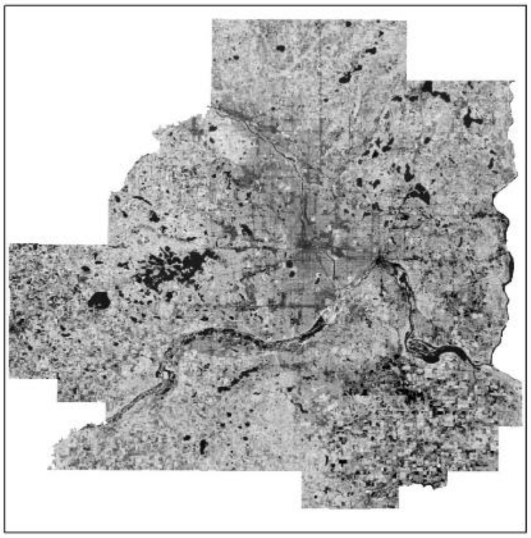


Figure 3. Landsat 8 Summer NDVI

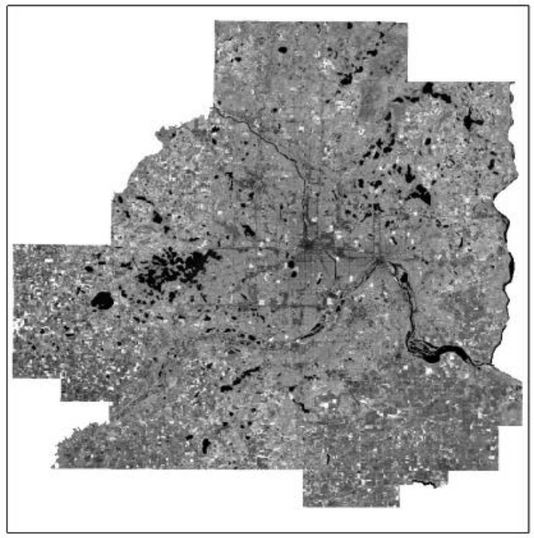
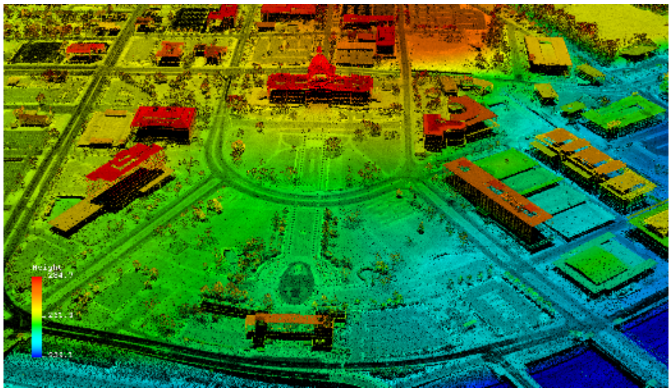


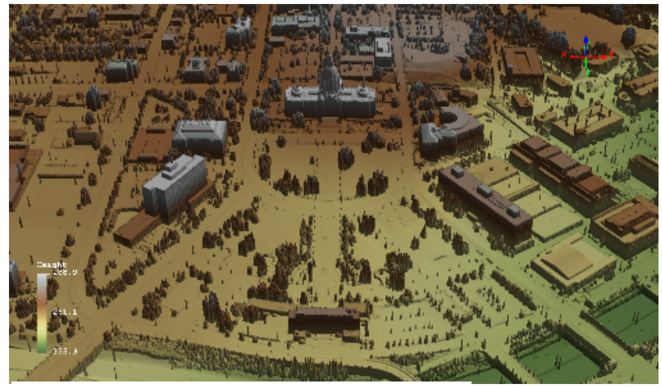
Figure 4. Landsat 8 Fall NDVI

2. Lidar Data Acquisition and Processing

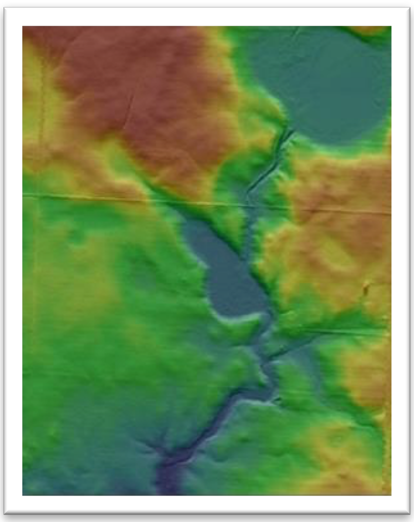
Lidar data collected for Minnesota between 2006 and 2012 publicly available by the Minnesota Department of Natural Resources (DNR). For more information, the 2011 Lidar metadata are available at: www.mngeo.state.mn.us/chouse/metadata/lidar_metro2011.html.
The DNR-provided 1-meter bare earth DEM was also used to create additional lidar-derived layers, such as Compound Topographic Index (CTI), slope, and normalized Digital Surface Model (nDSM). The U-Spatial - Support for Spatial Research, University of Minnesota provided a Digital Surface Model (1m resolution) for the state of Minnesota. The vertical accuracy of the Lidar data meets or exceeds 12.5 cm RMSE. Examples of the Lidar derived data are shown in Figure 5.



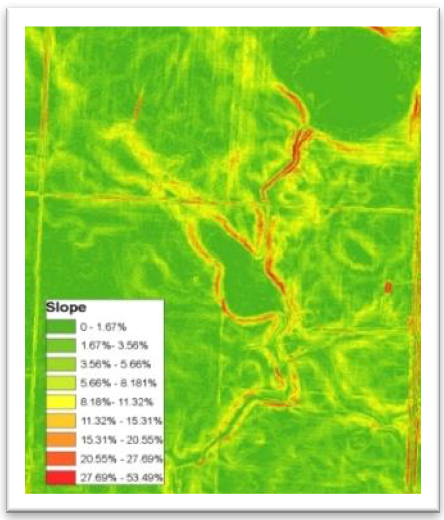
Point Cloud



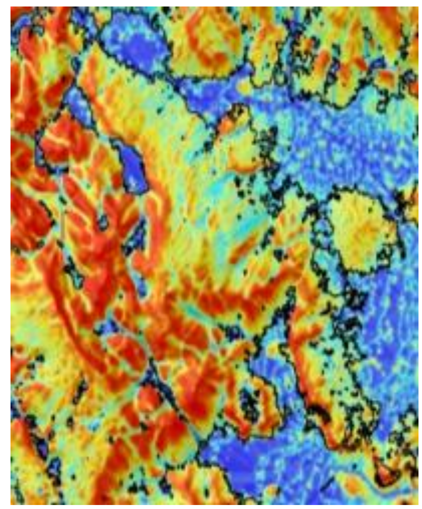
Digital Surface Model (DSM)



Digital Elevation Model (DEM)



Slope



Compound Topographic Index (CTI)

Figure 5. Examples of the lidar derived data

3. Additional Ancillary data

Additional ancillary vector layers included major roads, city streets from the Minnesota Department of Transportation, airport runway, railroad center lines, DNR Lidar building footprints and the updated National Wetlands Inventory (NWI). Further information about the updated NWI is available at http://www.dnr.state.mn.us/eco/wetlands/nwi_proj.html Examples of the ancillary data are shown in Figure 6 and 7.

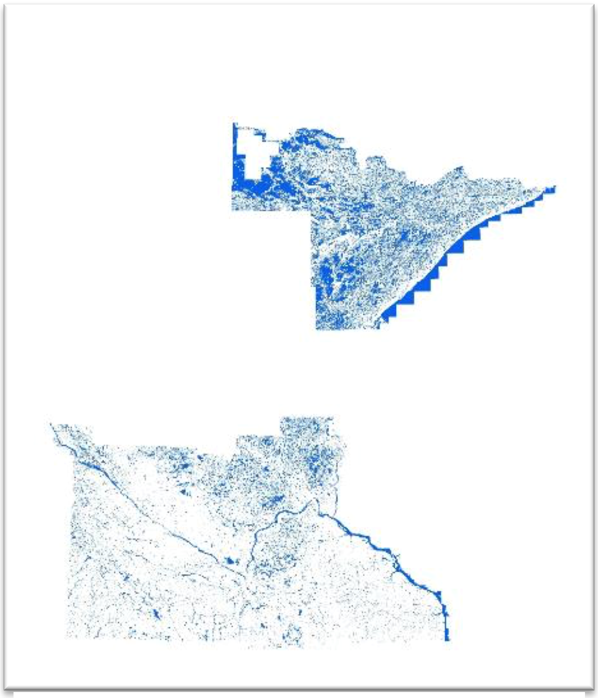


Figure 6 Updated NWI vector layer for Minnesota

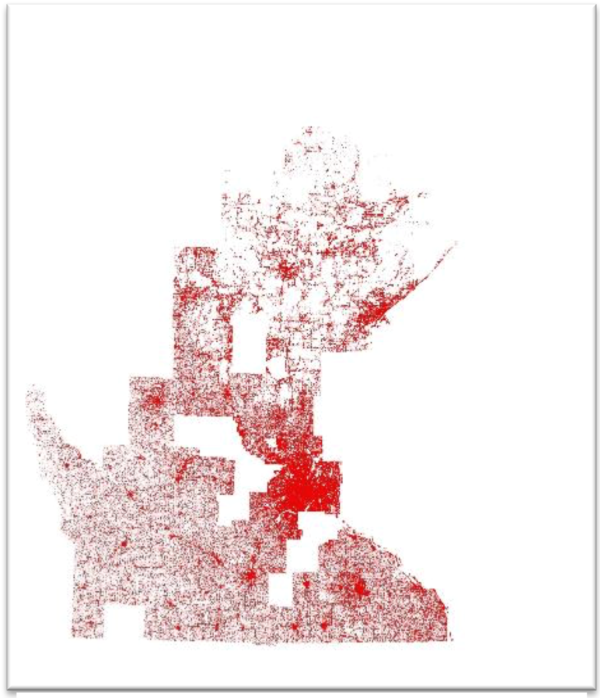


Figure 7 DNR Lidar Building footprints vector layer

4. Classification Scheme and Reference Data

An important element of any land cover classification project is the classification scheme, a systematic inventory of the classes of interest. For the statewide land cover classification, project we utilized a level 2 exhaustive and detailed classes. The classes are similar to those used for previous classifications of the Minnesota statewide, with a slight modification for wetland types because of the newly available and accurate National Wetlands Inventory data. The Level 1 and Level 2 classes are listed in Table 1.

Table 1. Classification scheme with Level 1 and 2 classes.

Level 1	Level 2	Code	Description
Urban / Developed	Impervious (%)	1-100	Roads, parking lots and building rooftops
Wetlands	Emergent Wetlands	101	(Palustrine PEM)
	Forested and Shrub Wetlands	102	(Palustrine PFO and PSS)
Open Water	Open Water	103	Lakes, Ponds and rivers
Extraction	Extraction	104	Pits, Quarries and Mines
Forest	Coniferous Forest	105	White Pine, Red Pine, Balsam Fir, Jack Pine, White & Black Spruce, White Cedar
	Deciduous Forest	106	Oak, Red Maple, Black Maple, Paper Birch, Black Ash, Aspen, Silver Maple
	Mixed Forest	107	Mixtures of Conifer and Deciduous
Managed	Managed Grass and	108	Golf courses, Parks, Natural grass and

Grass/Natural Grass	Natural Grass		Herbaceous vegetation
Agriculture	Hay and Pasture	109	Alfalfa and other hay and pasture
	Row Crops	110	Annual crops such as corn, soybean, Wheat, Oats, Barley and perennial crops

Reference Data: Reference data used for classifier training and accuracy assessment were created using high-resolution aerial photos available through the MnGeo Geospatial Image Service (www.mngeo.state.mn.us/chouse/wms/geo_image_server.html), 3-band 1-meter, 4 bands meter natural color and color-infrared USDA National Agricultural Program Imagery (NAIP) and Spring Aerial Imagery 4-band leaf-off (2009-2014). For classes, such as extraction and agriculture, ancillary datasets were used to identify characteristic areas for training. An example of NAIP imagery with examples of different cover type classes is shown in Figure 8.

Figure 8. NAIP image with examples of cover type classes.

5. Image Classification

We mapped 11 land cover classes: Deciduous Forest, Coniferous Forest, Mixed Forest, Grassland, Hay and Pastures, Row Crops, Extraction, Urban/Developed, Emergent Wetland, Forested/Shrub Wetland, and open water (ponds, lakes and rivers).

We employed an Object Based Image Analysis (OBIA) approach by creating rule sets for the seven ecoregions within the State of Minnesota. We used the Cognition Network Language (CNL) within the software package Definiens eCognition Developer version 9.1.0 was used to develop the rule sets. Each rule set was developed through a trial and error process using small subset areas. We used a divide and conquer approach, which is a multiscale iterative technique where objects vary in size, shape, and spectral attributes. Although the two major steps performed in the rule set development were the creation of objects and the classification of those objects, additional steps were required for the classification of each object to be assigned to the class of interest. Each rule set consisted of six key components: (a) image processing, (b) Masking out objects using a vector layer, (c) segmentation (c) classification, (d) export operations, and (e) cleanup operations.

In the image processing phase, we executed the following tasks: calculation of the normalized Digital Surface Model (nDSM) = DSM-DEM, creation of nDSM filtered layer, and a computation of a nDSM slope layer. Given the availability of the recently available new high resolution and accurate National Wetlands Inventory (NWI) 2010-2015 data for the southern part of the state; we masked all the water bodies including wetland types, lakes, rivers and ponds. We used the Chessboard segmentation algorithm in eCognition for masking out these features. Also, for the entire state we masked the roads, railroads, and airports; vector layers were obtained from the Minnesota Department of Transportation (MnDOT). Examples of segmentation results and objects are shown in Figure 9.

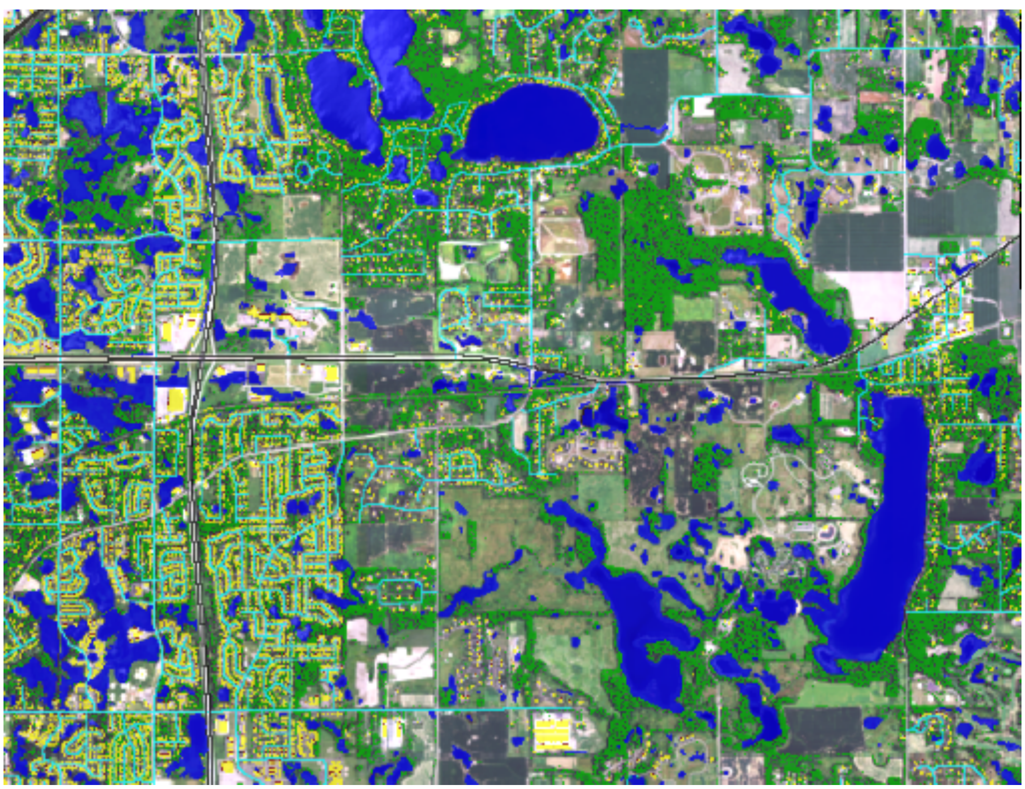


Figure 9. Initial object based segmentation based on thematic layers and Lidar data (Height): Wetlands, buildings, roads and forest

Classification: We classified preliminary objects (short versus tall) into temporary classes. The nDSM layer was used to separate short objects from tall objects. We executed the multi-threshold segmentation algorithm with the following parameters: a threshold value of equal or greater than 3 meters for tall object (potential tree canopy) and anything less than 3 meters for short objects. Previous parameters were determined after several trial-and-error experiments and a detailed visual assessment for separating short versus tall classes.

The temporary tall objects were merged and a new segmentation step was applied to these temporary objects. For this step, a multiresolution segmentation algorithm was employed for segmentation with the following parameters: Image layer (Green, Red and NIR leaf-on only), scale parameter: 100, shape: 0.1 and compactness: 0.3. The refined tall objects were classified as deciduous, conifer or mixed forest classes using the Random Forest (RF) algorithm within eCognition.

The RF is an ensemble learning method for classification that operates by constructing multiple decision trees. Each tree is grown from different random subsamples of the training data and during the split selection process uses a subsample of the available features. It allows for the use of a large number of features or variables and identifies the important predictors. We used all the features layer values from the spectral data to train the algorithm and classify the objects.

Finally, the remaining objects that were not classified as a type of water body or forest were merged and a new segmentation was performed. The following parameters were used for this segmentation: spectral bands (Green leaf-off and leaf-on, NIR leaf-off and leaf-on, Red leaf-off and on, Short-wave Infrared (SWIR)1 leaf-off and leaf-on and SWIR2 leaf-off and leaf-on); Scale parameter: 150, shape: 0.1 and compactness: 0.3. These new objects were classified using the RF algorithm as one of the following classes: Grassland, Hay and Pastures, Row Crops, Extraction, Urban/Developed and water bodies (wetlands or open water) for the part of the state that didn't have the updated NWI.

These features characteristics were used to train the RF algorithm: spectral and Lidar data values including min. and max. pixel values, means and standard deviations of individual bands; imagery brightness mean and differences; geometry including asymmetry, compactness, density, rectangular fit, roundness, area, length, number of pixels, and shape index; texture, including, homogeneity, contrast, dissimilarity, mean, and standard deviation; relations to neighbor objects including relative border to each class. In the export operation phase, we exported the final classes into raster and vector formats.

5. Estimation and Mapping of Impervious Surface Area

Estimation and Mapping of Impervious Surface Area for the objects classified as urban or developed, was done by running a regression model relating to the Landsat greenness variable to percent of imperviousness (Bauer, et al., 2007). This was developed to estimate and map the percent impervious surface area at the pixel level. Greenness is sensitive to the amount of green healthy vegetation and inversely related to the amount of impervious surface area.

Impervious was treated as a continuous variable from 1 to 100 percent, but can be grouped by the user into classes such as 1 - 10, 11- 25, 26 - 40, 41 - 60, 61 - 80, and 81 - 100 percent impervious. Figure 11 compares an aerial image and the Landsat classification of percent impervious.

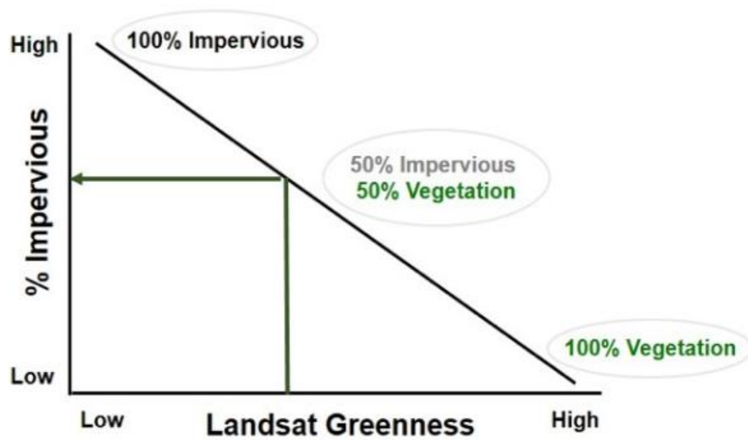


Figure 10. Basic theory for Landsat mapping of impervious surface area

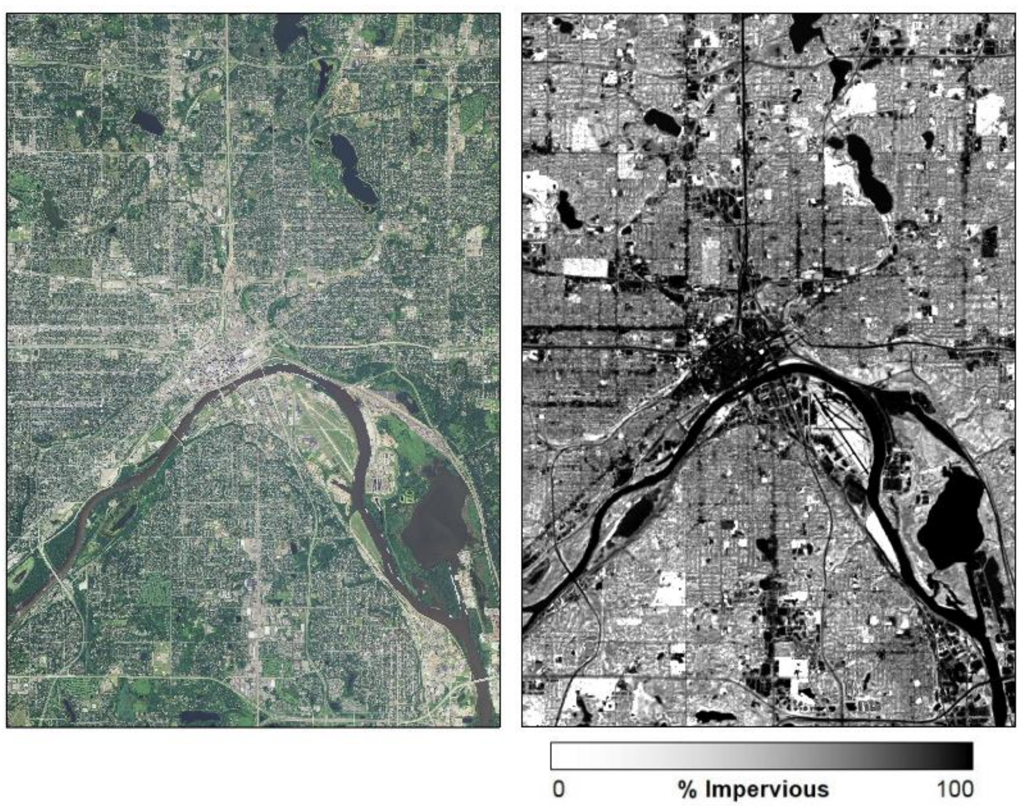


Figure 11. Comparison of aerial image and Landsat 8 classification of percent impervious for the St. Paul area.

6. Accuracy Assessment

Accuracy assessment was evaluated by comparing the classification results to an independent stratified random reference set of 19,532 points and reporting the error matrix and statistics derived from it. These included overall accuracy, user and producer accuracies for each class, and Kappa statistic (Congalton and Green, 2009).

7. Results

The primary output of the project is the land cover classification map for the entire state of Minnesota in a raster format. The overall classification of the state of Minnesota is shown in Figure 12.

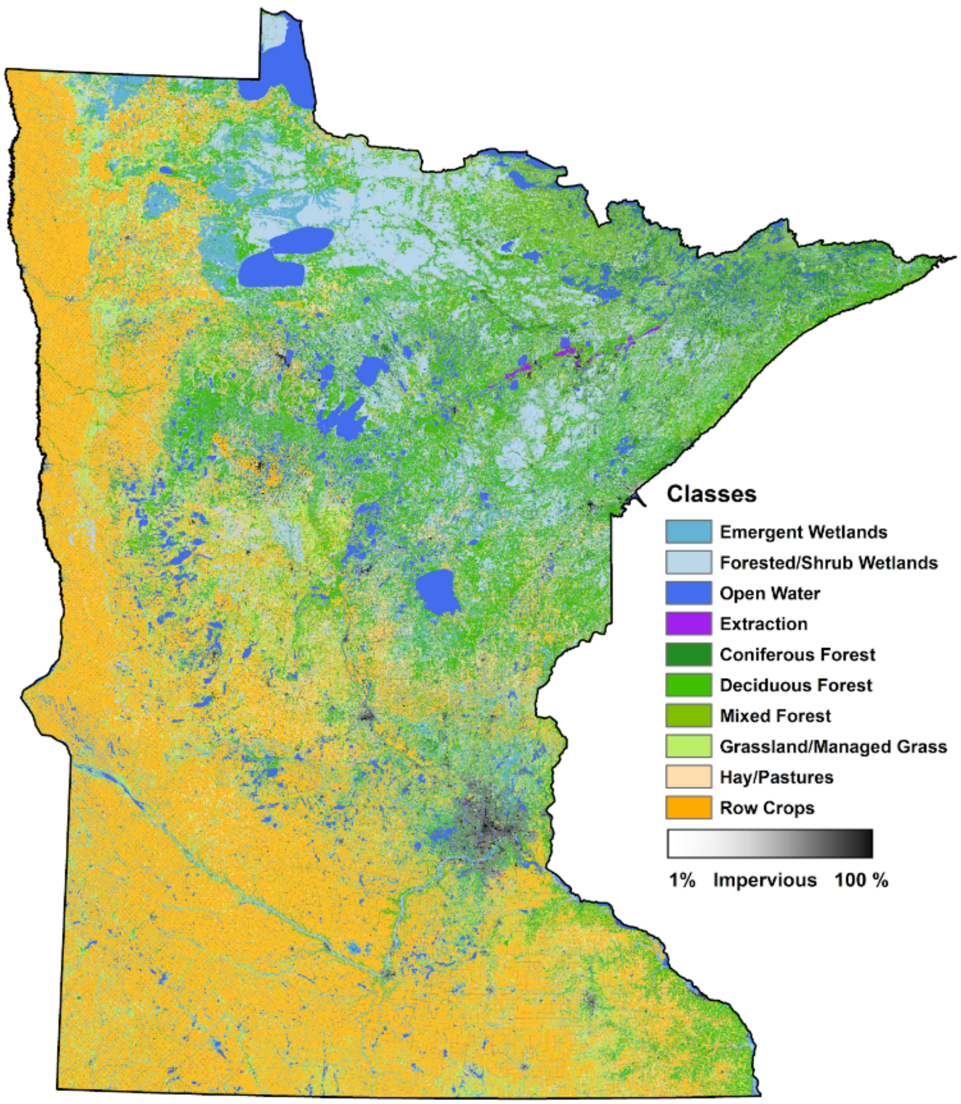


Figure 12. Minnesota Statewide Level 2 land cover classification

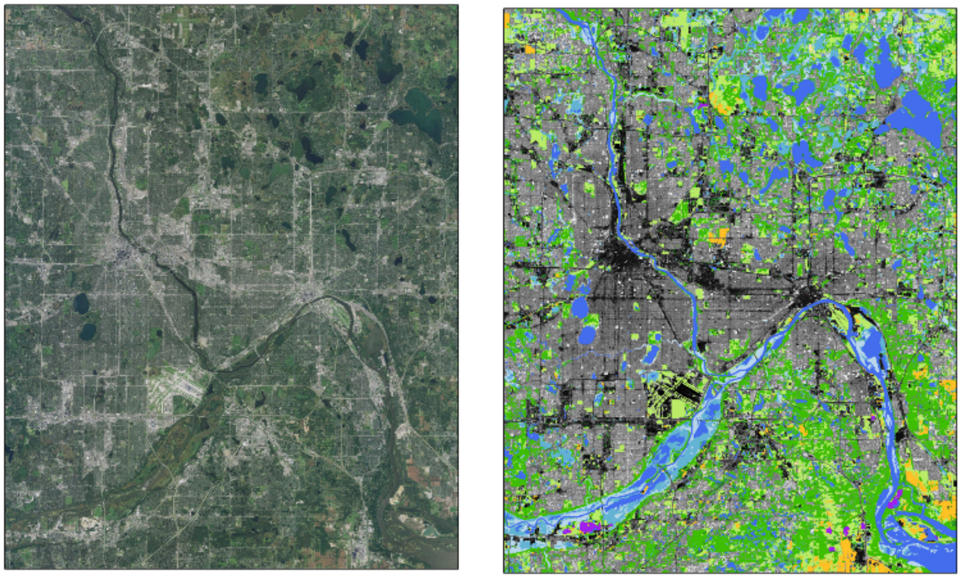


Figure 13 Downtown St. Paul, MN showing high percentage of impervious surface

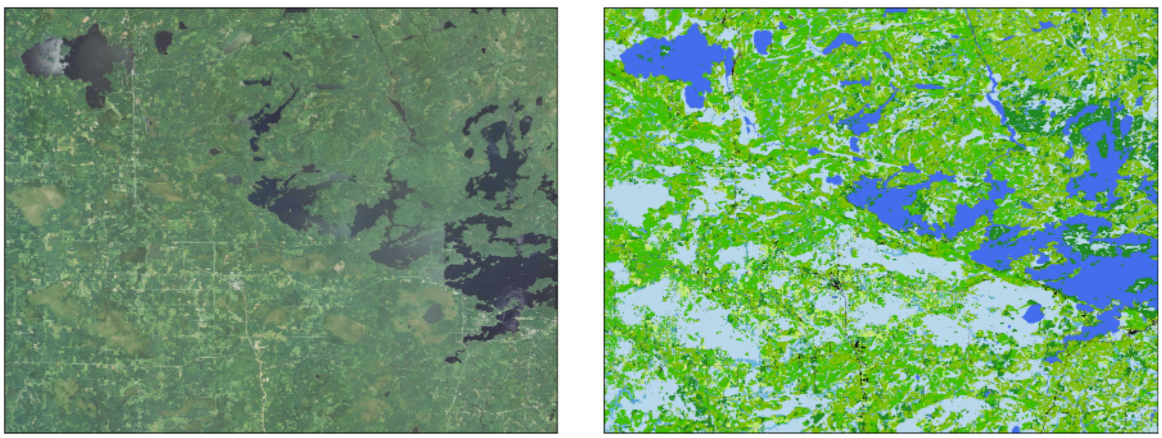


Figure 14 A section of the Boundaries waters canoe area wilderness showing different types of wetlands

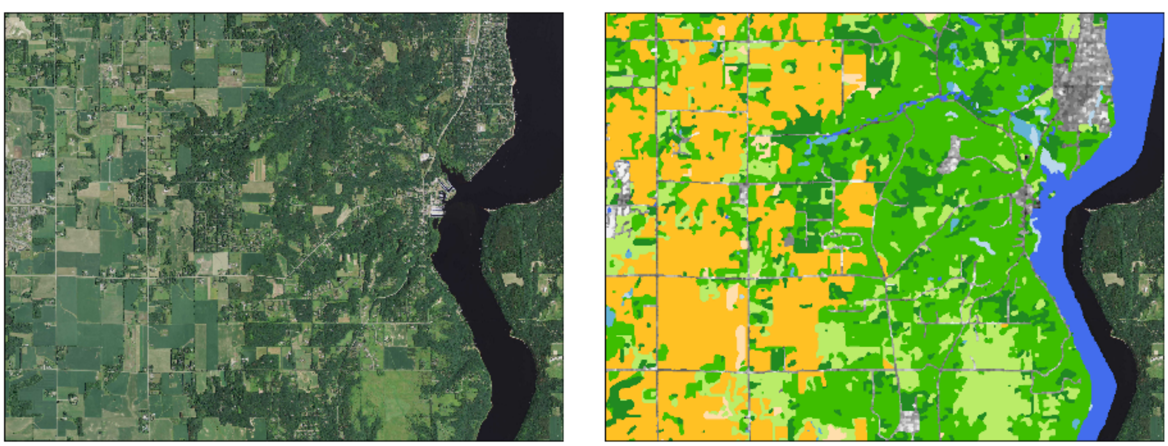


Figure 15 Coniferous and Deciduous forest type, Washington County, MN

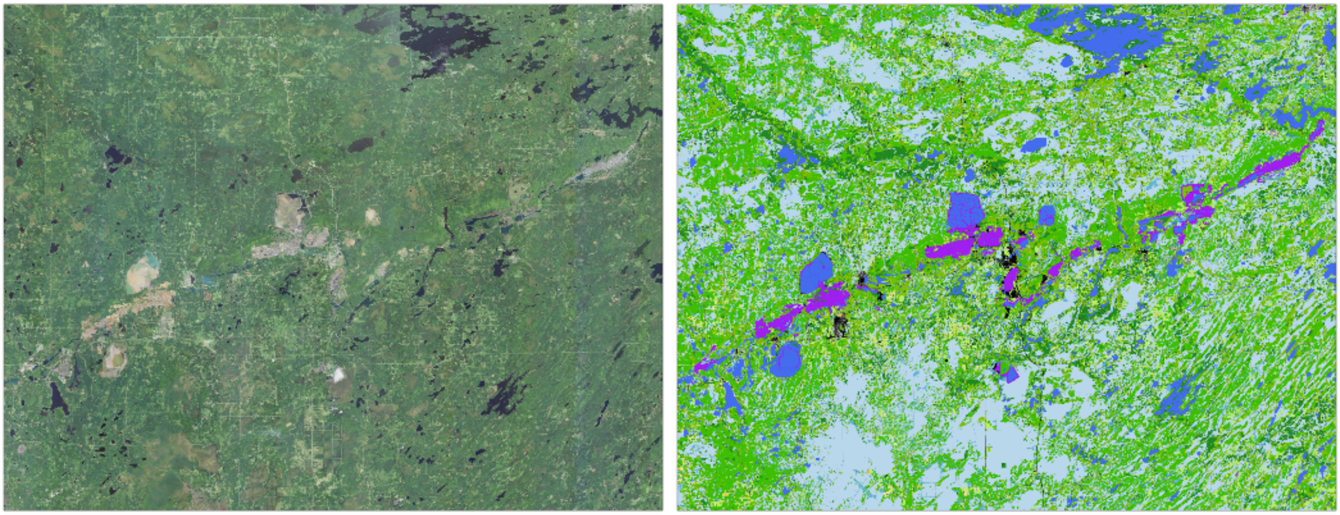


Figure 16 Iron range of the Lake Superior region, MN

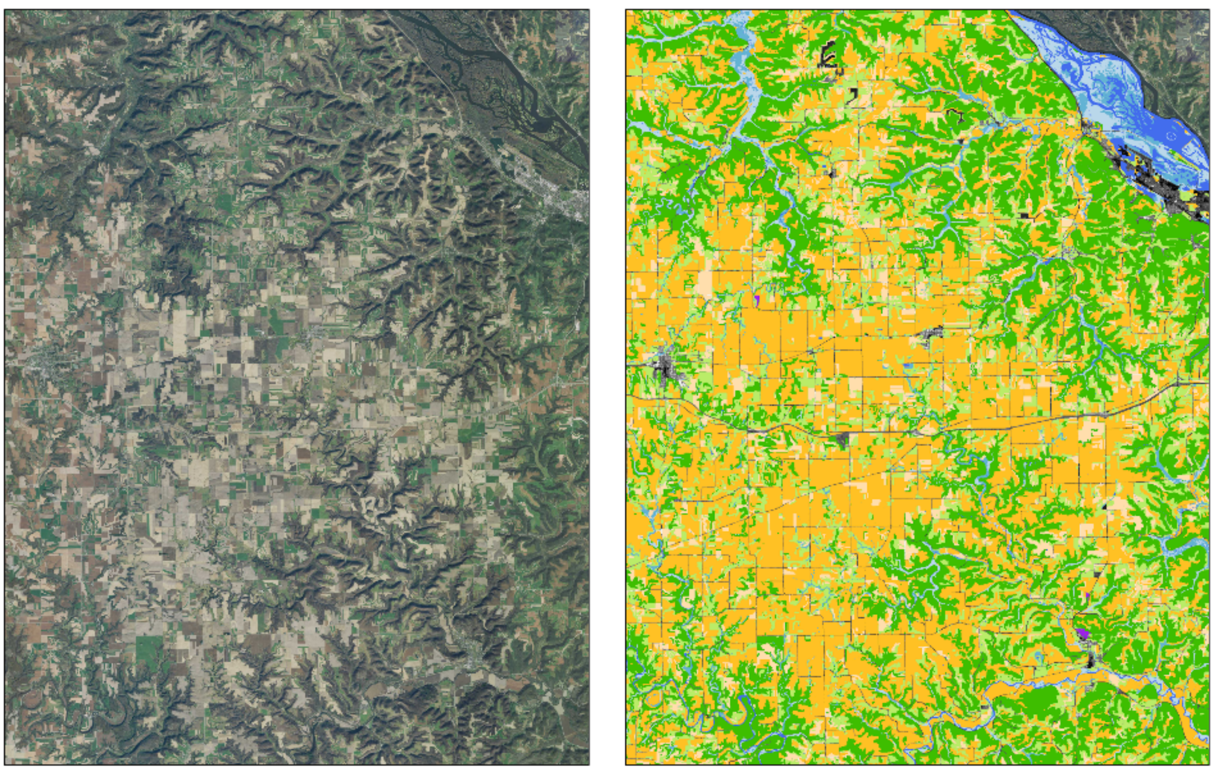


Figure 17 Southern MN dominated by agricultural land cover

Qualitatively, the Land cover classification (Figures 13 - 17) compared to the high-resolution images shows a high correspondence between them. Table 2 – 6 show the quantitative accuracy assessment results including the independent stratified random reference set of 19,532 points and reporting the error matrix, overall accuracy, user and producer accuracies for each class, and Kappa statistic. We attribute this to the use of the object-based classification and combination of Lidar derived products with multispectral data. The accuracy assessment results do not include water and wetlands for the areas that updated NWI was available. The wetland and water class was assessed only for the part of the state that did not have the updated NWI layer available when this classification was produced. The data set has an overall classification accuracy of 97% for level 1 and 96% for level 2 land cover classifications.

Table 2. Confusion Matrix - Summary.

	Open Water	Wetlands	Forest	Grass	Agriculture	Developed	Extraction	Total
Open Water	965	6	2	0	0	0	2	975
Wetlands	2	4158	97	7	30	1	1	4296
Forest**	0	104	4087	10	13	1	0	4215
Grass/Shrub	1	19	14	1126	82	7	0	1249
Agriculture	0	8	14	47	6961	5	0	7035
Developed*	0	0	6	1	14	1681	0	1702
Extraction	0	0	0	1	0	0	53	54
Totals	968	4295	4220	1192	7100	1695	56	19,526

* Developed is an aggregation of Buildings, Bare soil, and Roads/other paved surfaces
** Forest is an aggregation of Deciduous and Coniferous tree canopy

Table 3. Level 1: Producer and User's accuracy

Class	User's	Producer's
Open Water	99%	99%
Wetlands	97%	96%
Forest	97%	96%
Grass/Shrub	90%	93%
Agriculture	99%	97%
Developed	99%	98%
Extraction	93%	95%

Table 4. Level 1: Overall and Kappa

Overall	97%
95% CI	92 - 98
Kappa	0.96
Kappa Variance	0.000002

Table 5. Level 2: Producer and User's accuracy

Class	User's	Producer's
Open Water	**99%**	99%
Emergent wetlands	80%	90%
Forested wetlands	97%	96%
Conifer Forest	90%	86%
Deciduous Forest	96%	97%
Mixed Forest	60%	81%
Grass/Shrub	90%	94%
Agriculture	99%	98%
Hay & Pasture	91%	89%
Developed	99%	98%
Extraction	93%	95%

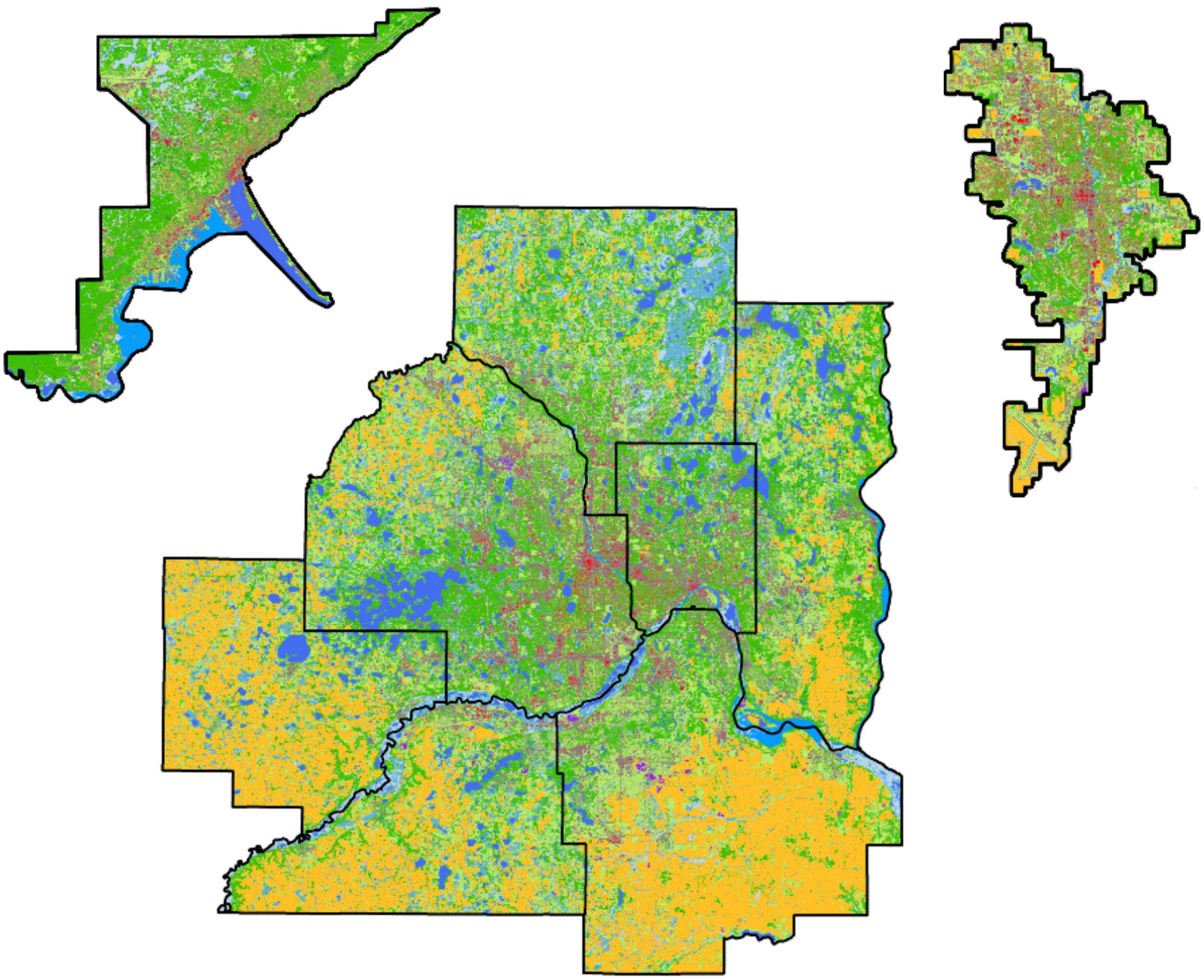
Table 6. Level 2: Overall and Kappa

Overall	96%
95% CI	96 - 97
Kappa	0.95
Kappa Variance	0.000003

Summary

A combination of multi-temporal Landsat data and Lidar data with object-based image analysis has been enabled accurate level 1 and 2 land cover classifications for 2011 with the Landsat and Lidar data providing synoptic views of the entire area. The classifications also include percent impervious area for the urban class. 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 by county, city/township, etc. The classification results have been provided to the Metropolitan Council as ArcGIS files. Maps and statistics in a web mapping application will be available at http://land.umn.edu.

Land Cover Classification at One-Meter Resolution



Rationale and Background

Current land cover information is critical for land use planning and environmental monitoring. Urban areas are comprised of complex surface features. Estimates of areal land cover are directly related to spatial resolution. In urban areas, there is a need for high resolution land cover data for planning and management. This data must also be frequently updated because of the rapid changes that occur in urban areas. As demand for spatial land cover data increases, larger areas must be mapped. To meet the spatial, temporal, and extent requirements for spatial data, remote sensing is the ideal tool for obtaining this data.

Remote sensing has long been found as a tool for monitoring and measuring large areas of land. Satellite or aerial imagery can be used to visually assess surface features. More advanced imaging sensors can obtain non-visible wavelengths such as near-infrared which allows calculation of indices such as NDVI - a well-documented and standardized measure of vegetation health. Lidar data also has become a critical data source for land cover by providing unique elevation, height, intensity, and structural information. The combination of aerial imagery and Lidar data allows very detailed and accurate land cover classification to be created.

The large amounts of input data require an automated approach and immense processing power. For high-resolution images, object based image analysis (OBIA) has been proved to improve accuracy over pixel-based approaches. Treating image features as objects reduces errors due to 'noise' and provides contextual elements such as texture, size, shape, and neighboring object relations. Additionally, iterative classification steps within in the OBIA method improve accuracy because distinguishable classes can be separated initially leaving less chance for error when classifying more complex classes. Parallel processing of the imagery and Lidar data can significantly reduce the processing time. This reduction in processing time allows repeated testing to produce the best classification map.

Methods

Data Inputs

Leaf on National Agriculture Inventory Program (NAIP) imagery was collected in the summer of 2015 at 1-meter resolution. Leaf off aerial imagery was collected in the spring of 2011 at 0.3-meter resolution. Both imagery sets include near-infrared, red, green, and blue bands. The Normalized Difference Vegetation Index (NDVI) was derived for the leaf on and leaf off imagery. The combination of leaf-on and leaf-off imagery with 4-bands and sub-meter spatial resolution allows detailed feature identification as well as phenological information critical to land cover classification.

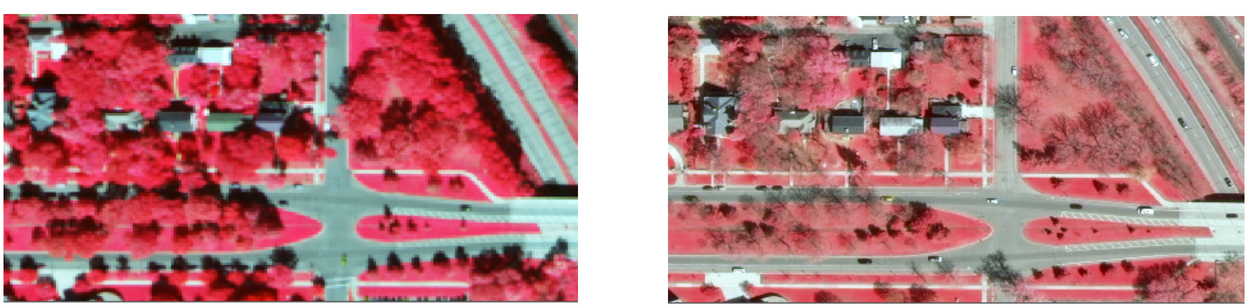


Figure 1: False color Infrared highlights healthy vegetation in pink for leaf-on summer condition (left) and leaf-off spring conditions (right)

Lidar data was collected for TCMA in 2011 and made publicly available by the Minnesota Department of Natural Resources (DNR). Lidar point density varies from 1.5 - 8 pulses/m^2 within the TCMA. LAStools was used to create 1-meter bare earth Digital Elevation Models (DEM), Digital Surface Models (DSM), and Lidar Intensity. A DSM was created using all relevant first returns with the spike-free method in las2dem with a freeze constraint of 3 meters. This method was chosen to avoid pits or gaps within tree canopy and to create a more continuous model of the surface features from the Lidar point cloud in order to match the one-meter imagery. Surface models are typically created using only Lidar first returns, however, at the highest resolution supported by the Lidar, some grid cells will have low values compared to neighboring cells where Lidar pulses have penetrated the tree canopy. The spike-free method creates a TIN surface from all the points and especially prioritizing points that are spatially proximate in the z dimension (Khosravipour et al.,2016). Additional Lidar-derivative layers, such as slope and normalized Digital Surface Model (nDSM) were created as well.

Vector layers: roads, railroads centerlines, and airports were obtained from Open Street Map and the Minnesota Department of Transportation (MnDOT). The OpenStreetMap data is available under the Open Database License, see: http://www.openstreetmap.org/copyright

The National Wetland Inventory (NWI) was used for water and wetland classes. For more information about the updated NWI data, see: http://www.dnr.state.mn.us/eco/wetlands/nwi_proj.html

Classification Scheme

A key component to a land cover classification product is the classification scheme, a descriptive listing of all classes present. This listing is exhaustive, mutually exclusive, and hierarchical. These classes were chosen to correspond with previous land cover classification products for this area where applicable. Higher spatial resolution allows the Urban/Developed class to be separated into Buildings, Bare Soil, and Roads/Paved Surfaces classes.

Twelve level-2 land cover classes were mapped: Deciduous Tree Canopy, Coniferous Tree Canopy, Grass/Shrub, Agriculture, Extraction, Buildings, Roads/Paved Surfaces, Bare Soil, Emergent Wetland, Forested/Shrub Wetland, Lakes, and Rivers.

Table 1: Classification scheme with Level 1 and 2 class descriptions.

Level 1	Level 2	Code	Description
Grass/Shrub	Grass/Shrub	1	Golf courses, Parks, Natural grass and Herbaceous vegetation
Urban/Developed	Bare Soil	2	Baseball fields, golf course sand traps
	Buildings	3	Commercial, residential, and all structures over 3 m tall
	Roads/Paved Surfaces	4	All roads, parking lots, sidewalks, and paved surfaces
Lakes/Ponds	Lakes/Ponds	5	Lacustrine L1, L2, Palustrine PAB, PUB, PUS
Tree Canopy	Deciduous Tree Canopy	6	Oak, Red Maple, Black Maple, Paper Birch, Black Ash, Aspen, Silver Maple
	Coniferous Tree Canopy	7	White Pine, Red Pine, Balsam Fir, Jack Pine, White & Black Spruce, White Cedar
Agriculture	Agriculture	8	Annual and perennial crops
Wetland	Emergent Wetland	9	Palustrine PEM

	Forested/Shrub Wetland	10	Palustrine PFO and PSS
	River	11	Riverine
Extraction	Extraction	12	Gravel pits, quarries, and mines

Classification Procedure

Data organization and pre-processing was important to manage over a Terabyte of raw imagery and Lidar data for the TCMA classification. Leaf-on 1-meter imagery was mosaicked into a single .img file (55 Gb) using ERDAS mosaic pro using geometry based seamlines. Similarly, leaf-off 0.3 m imagery was mosaicked into a single .img file (550 Gb). Spectral indices (such as NDVI) were created for both sets of imagery. Digital surface models were created from the Lidar point cloud using LAStools to match the 1-meter resolution imagery. The imagery and Lidar data were previously georeferenced. An eCognition workspace was set up using 3,172 quarter-quad Lidar LAS point cloud tiles (500 Gb). This was done to allow parallel processing of tiles reducing the temporary memory usage and increasing processing time 16-fold. The first step in the ruleset (explained below) is to reference these data sources for each individual tile.

An Object Based Image Analysis (OBIA) approach was utilized by creating rule sets for the selected areas within the State of Minnesota. We used the Cognition Network Language (CNL) within the software package Definiens eCognition Developer version 9.2.0 was used to develop the rule sets. A similar land cover ruleset was adapted to create the land cover classification. This process began by classifying the most easily separable classes and worked toward the more complex classes that were more difficult to separate. New rules were developed to classify agriculture, extraction, and to separate tree canopy type into deciduous or coniferous tree types. The ruleset uses a divide and conquer approach to mask out easily separable classes to avoid errors. For example, the nDSM layer was used to identify all pixels greater than 3 meters as "_Tall" (temporary class). Subsequent classes were classified from only the remaining unclassified pixels effectively masking out all pixels/objects already assigned to a class. This means that the order of the rules for each class is critical to avoid errors. The classification structure used in our ruleset follows the following order:

1. Lakes, Rivers, Emergent Wetland, Forested/Shrub Wetland – imported from the updated NWI shapefile. Given the availability of the recently available new high resolution and accurate NWI 2010-2015 data for the Northeast and Southern part of the state; we masked all the water bodies including wetland types, lakes, rivers and ponds. We used the Chessboard segmentation algorithm in eCognition for masking out these features.

2. Buildings: The Lidar building footprints was used as the initial vector layer to classify buildings. Threshold segmentation was used then to create temporary "Tall" class from the Lidar nDSM with values larger than 3 meters. Additional rules were created using spectral and contextual information to classify buildings that were not identified by the Lidar building footprints layer. One useful object attribute was Lidar first-last return difference since individual Lidar pulses will not penetrate buildings as well as tree canopy resulting in differing values. Buildings have first-last return near 0. Rules were experimentally tested on subset areas to determine the appropriate value.

3. Tree Canopy - Coniferous vs. Deciduous: A series of rules then separated the "Tall" class into the Tree Canopy class or the Building class using image segmentation to create image objects which were then classified by optical image characteristics (NDVI, brightness, etc.) and Lidar point cloud properties (number of returns, intensity, etc.). Coniferous and deciduous were classified

from the tree canopy class using optical properties, NDVI, and the difference in NDVI between leaf-on and leaf-off imagery.

4. Extraction: a mining, gravel pits, and quarries location point vector layer was used as the starting base information to identify potential extraction locations. Further refinement of this class was completed using customized rules along with spectral and contextual information.

5. Impervious (roads/other paved): OpenStreetMaps roads vector layer was used as the initial identification of roads which were then verified using optical properties of the imagery. Other paved surfaces were classified by object features distance to roads and building classes as well as object size, shape, and optical characteristics.

6. Agriculture: we used a customized polygon vector layer to identify initial potential classes for agriculture areas. This vector layer contained row crops, hay and pastures classes that were derived from Landsat 8 imagery which allowed us to use many multispectral bands and multitemporal images using the Random Forest (RF) algorithm within eCognition. Further enhancement of this class was finalized using customized rules that made use of spectral and contextual information (association, size, shape, and pattern).

7. Bare Soil: A polygon vector layer from OpenStreetMap's was used to identify potential areas of bare soil based on land use context which was then verified by optical characteristics from the NAIP imagery.

8. Grass/Shrub: Grass/shrub was the most widespread and spectrally diverse class in the landscape, so a process of elimination was used for this final class. After all other land cover classes have been identified, the remaining unclassified objects were classified as grass/shrub.

9. The final classification was then exported as an .img raster file for each tile. ERDAS mosaicpro was used to merge the final rasters into one final TIF raster format with LZW compression to conserve disk space.

10. Class area statistics were calculated using ERSI ArcGIS (Zonal statistics to table).

Results

The raster classification is depicted in Figure 2. This report includes the overall area estimates for each class in number of acres and in proportion to the total (Table 2). Areal estimates of land cover classes can be calculated for a given area from the classification. ESRI ArcGIS zonal statistics tool was used to compute area estimates from the raster classification. This report includes the overall area estimates for each class in number of acres and in proportion to the total.

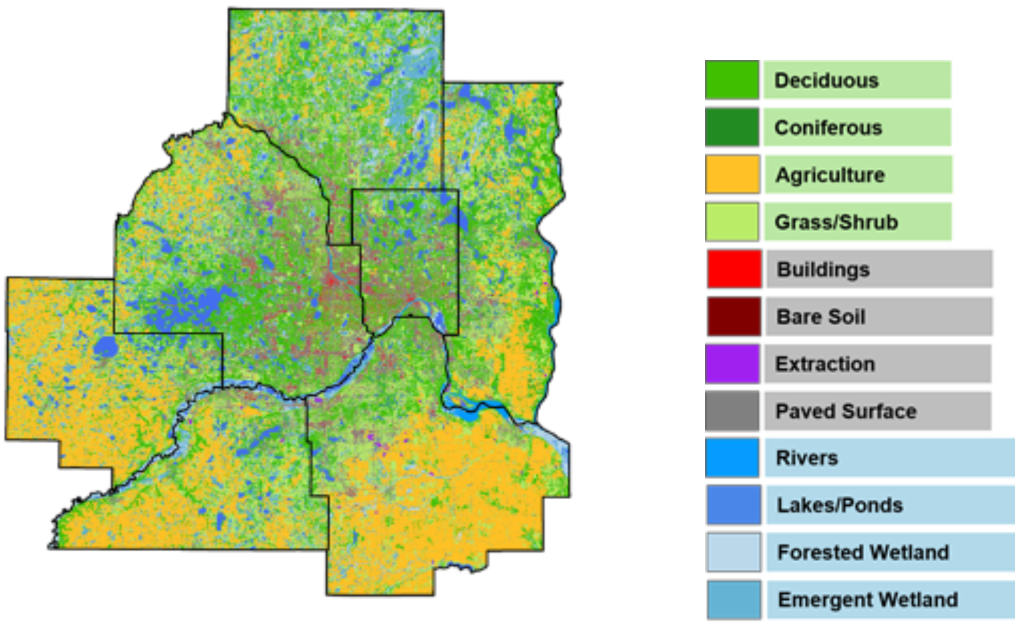
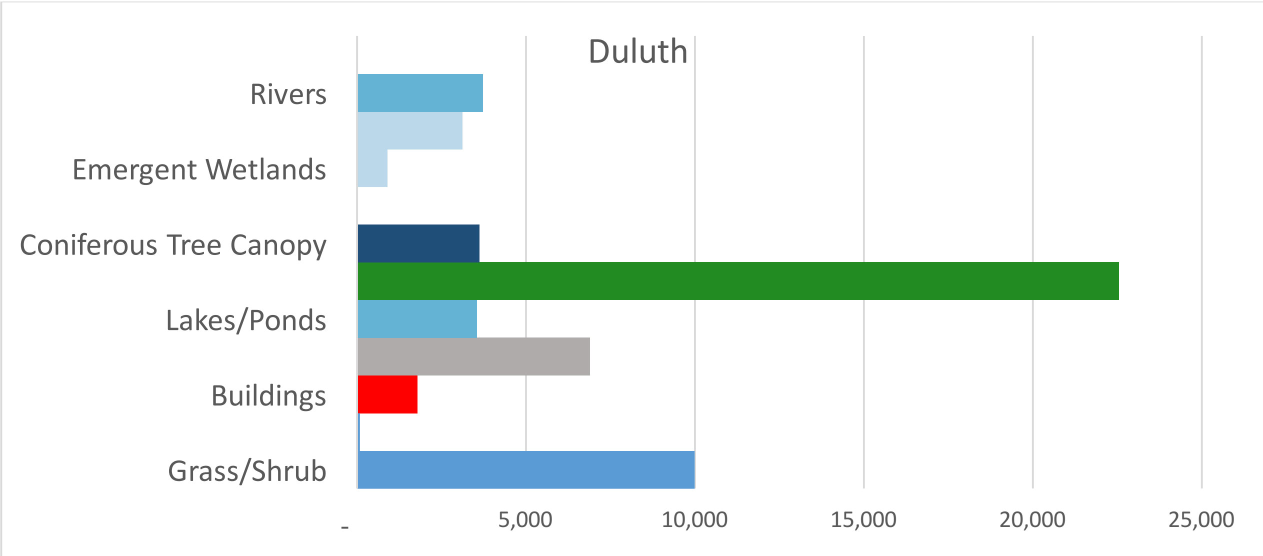


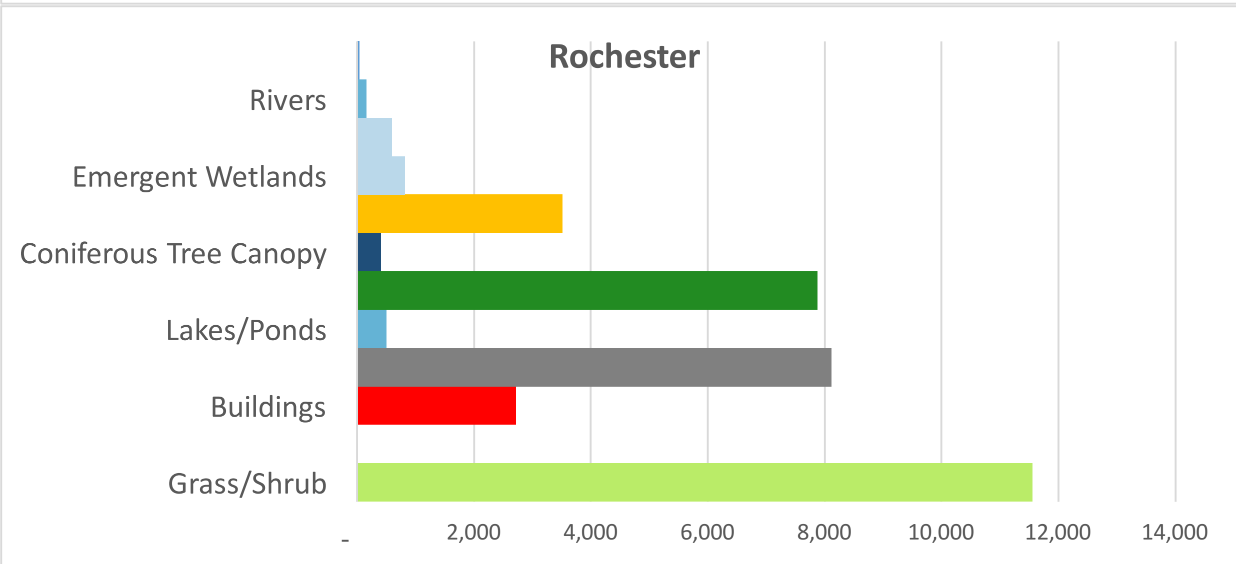
Figure 2: Twin Cities Metropolitan Area 12-class land cover canopy classification.

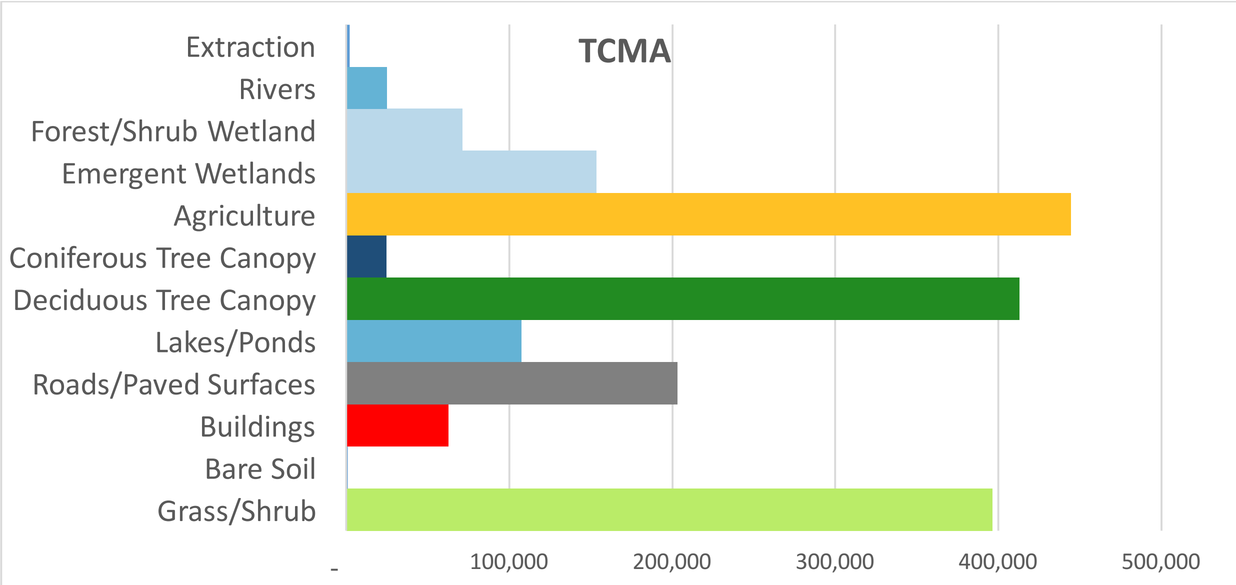
Table 2: Land cover statistics by class, aggregated level one (left), full classification (right)

Class Name	Area (acres)	Proportion
Grass/Shrub	396,212	21%
Urban	268,969	14%
Tree Canopy	437,342	23%
Agriculture	444,454	23%
Water	132,215	7%
Wetland	224,602	12%
Total	1,903,794	100%

Class Name	Area (acres)	Proportion
Grass/Shrub	396,212	21%
Bare Soil	1,075	0%
Buildings	62,702	3%
Roads/Paved Surfaces	203,059	11%
Lakes/Ponds	107,479	6%
Deciduous Tree Canopy	412,791	22%
Coniferous Tree Canopy	24,551	1%
Agriculture	444,454	23%
Emergent Wetlands	153,431	8%
Forest/Shrub Wetland	71,171	4%
Rivers	24,736	1%
Extraction	2,133	0%
Total	1,903,794	100%


Duluth
Rivers
Emergent Wetlands
Coniferous Tree Canopy
Lakes/Ponds
Buildings
Grass/Shrub
-
5,000
10,000
15,000
20,000
25,000


Rochester
Rivers
Emergent Wetlands
Coniferous Tree Canopy
Lakes/Ponds
Buildings
Grass/Shrub
-
2,000
4,000
6,000
8,000
10,000
12,000
14,000



TCMA
Extraction
Rivers
Forest/Shrub Wetland
Emergent Wetlands
Agriculture
Coniferous Tree Canopy
Deciduous Tree Canopy
Lakes/Ponds
Roads/Paved Surfaces
Buildings
Bare Soil
Grass/Shrub
-
100,000
200,000
300,000
400,000
500,000

Figure 3. Detailed view of the Leaf-On imagery (left) and Classified image (right).

Figure 4. Urban downtown St. Paul.

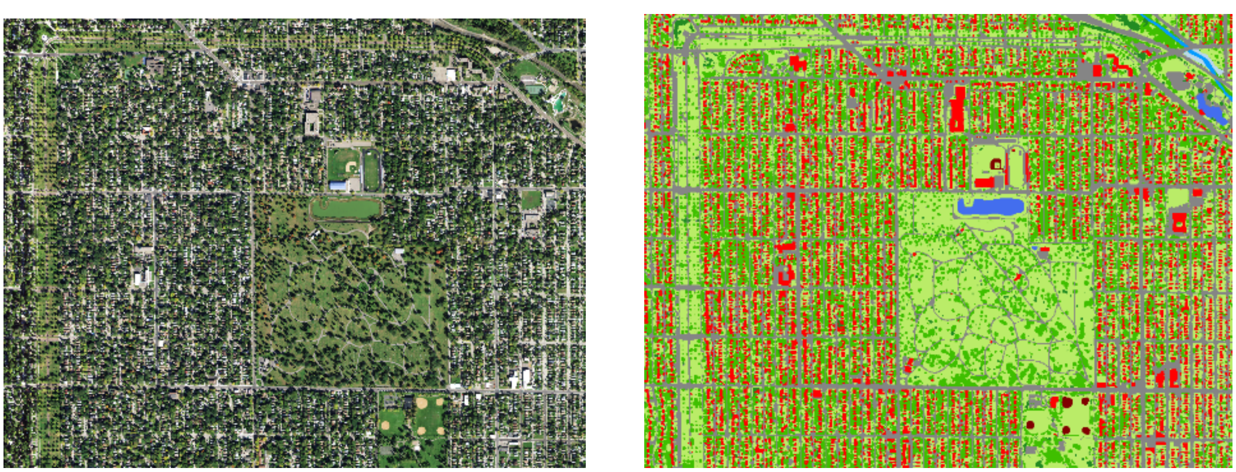


Figure 5. Residential Minneapolis neighborhood.

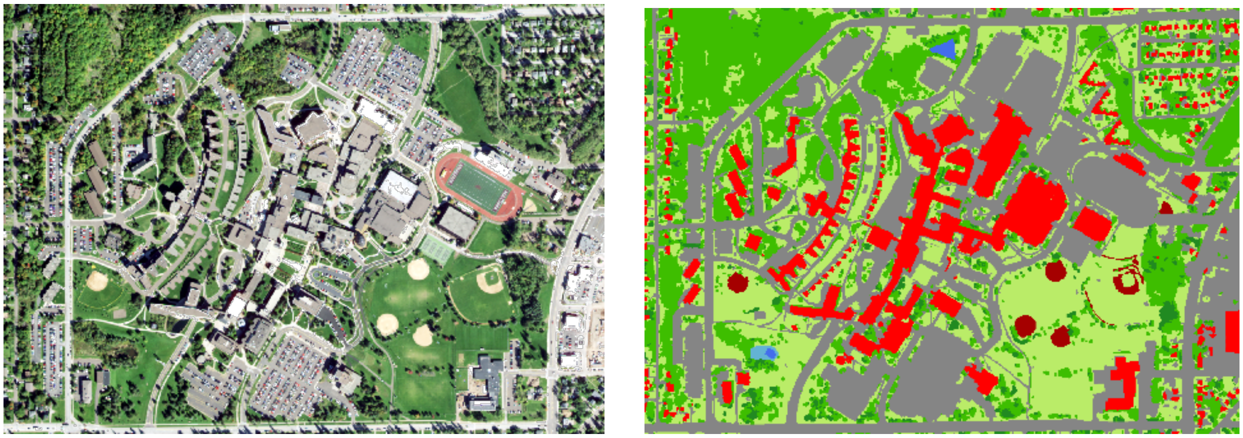


Figure 6. University of Minnesota – Duluth campus.

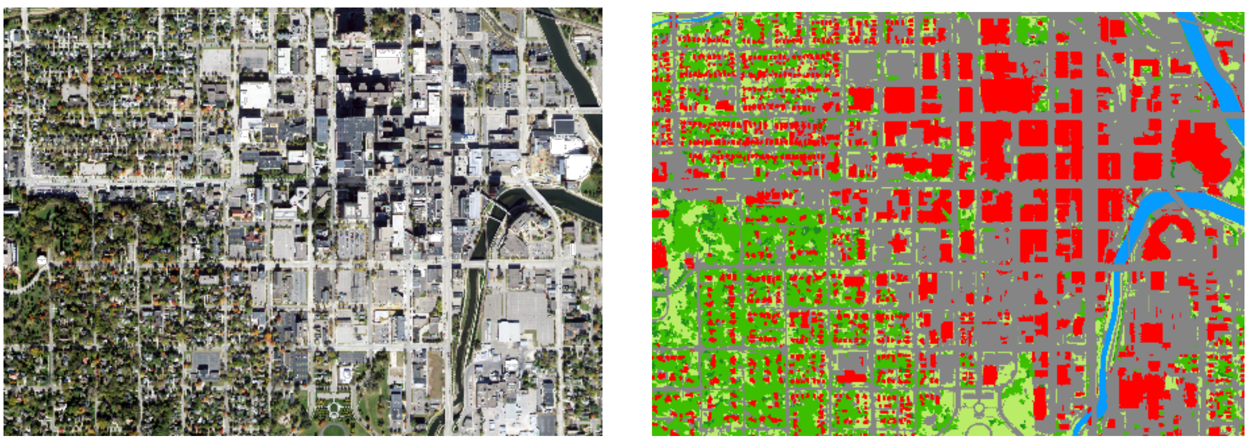


Figure 7. Urban Rochester downtown.

Accuracy Assessment

Accurate reference data with a higher resolution than the classification product is typically used to verify the accuracy of the classes represented. Since higher resolution data was not available, classification accuracy was evaluated by independent per-pixel analysis of the two dates of optical imagery and LiDAR-derived products. Stratified random points were generated encompassing each study area. In total, 1,547 points were generated - TCMA: 1,097; Duluth: 295; and Rochester: 155. Differences in number of points are relative to the extent of classified area. Accuracy assessment points were independently verified by manual image interpretation from both leaf-on and leaf-off imagery datasets as well as the LiDAR nDSM. Water and wetland classes were independently assessed by the National Wetlands Inventory and were excluded from this assessment. The assessment points were identified as Urban, Extraction, Deciduous Tree Canopy, Coniferous Tree Canopy, Agriculture, and Grass/shrub. The Buildings, Paved Surfaces, and Bare Soil classes had to be aggregated to compare to the Urban assessment points. Tree Canopy was assessed both at level one (Tree Canopy) and level two (Deciduous vs. Coniferous). A confusion matrix was created to compare reference points to the classified map points.

Figure 8: Assessment points were sometimes difficult to manually interpret when landing on the edge of tree canopy and buildings such as the image above.

The overall level one accuracy for each region were as follows: TCMA = 88%; Duluth = 89%, and Rochester = 92%. The full user's and producer's accuracies are reported in Table 4. An error matrix was created from the accuracy assessment points. The majority of errors were misclassification of tree canopy as grass/shrub which occurred at 42 points out of 515 total. The Grass/shrub class had the most confusion with a user's accuracy of 81% and producer's accuracy of 78%.

Figure 9: Locations of 1,097 stratified randomly distributed assessment points, green = correctly classified; red = incorrectly classified.

Table 3: Summarized Error Matrix (for error matrix by area see appendix)

Summary	Reference						
Classification	Developed	Extraction	Tree Canopy	Grass/Shrub	Agriculture	Total	**User's**
Developed	398	4	2	15	0	419	**95%**
Extraction	0	14	0	0	0	14	**100%**
Tree Canopy	19	0	453	42	1	515	**88%**
Grass/Shrub	35	0	22	281	11	349	**81%**
Agriculture	1	0	1	20	229	251	**91%**
Totals	453	18	478	358	241	1,548	
Producer's	**88%**	**78%**	**95%**	**78%**	**95%**		

Summarized overall accuracy = 89%
Duluth overall accuracy = 89%
Rochester overall accuracy = 94%
TCMA overall accuracy = 88%

Discussion

One of the biggest issues was time differences between the image collections and LiDAR acquisition. LiDAR acquisition occurred in 2011 while imagery was collected in 2015. These led to some discrepancies in the final land cover classification and tree canopy assessment. Loss of trees due to new development was difficult to accurately map.

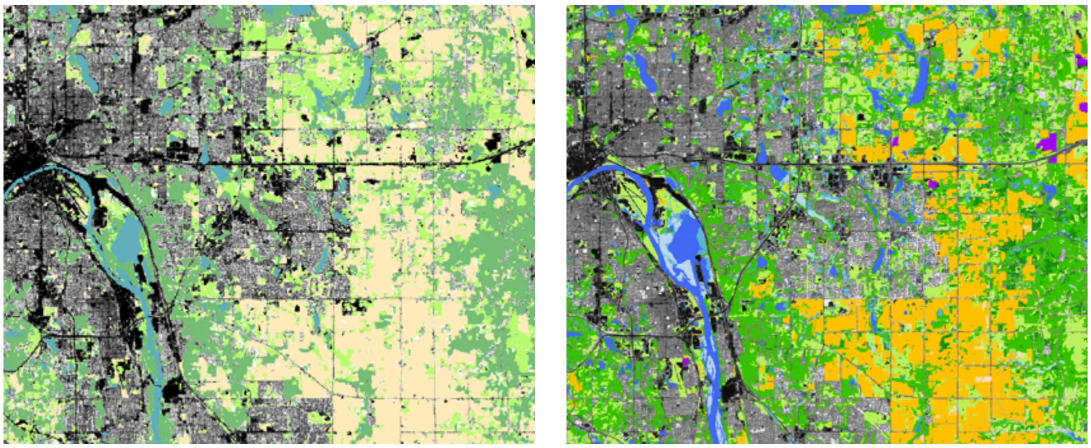
In addition to discrepancy in dates, LiDAR data was collected in different seasons and different point densities. Deciduous tree canopy in leaf-off conditions do not provide as many pulse returns as leaf-on canopy so the canopy is likely to be underestimated. The spike-free interpolation method improved this issue but in areas with low point density, the DSM height estimates were more isolated than the aerial imagery suggested. Tree canopy in Northern Dakota county was the most impacted by this effect.

Summary and Conclusions

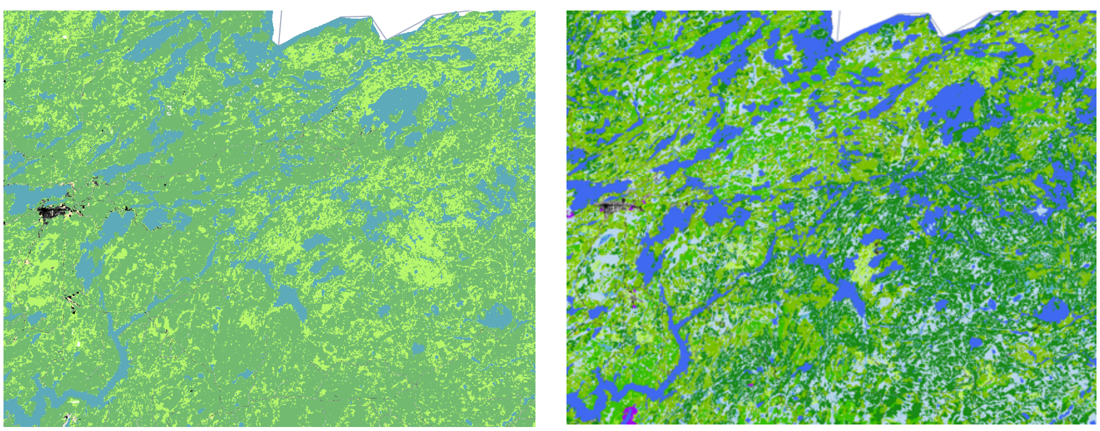
High-resolution imagery can provide detailed information about complex urban landscapes but challenges arise with processing and managing large volumes of data. The combination of spectral data and LiDAR through an OBIA method helped to improve the urban tree canopy assessment overall accuracy results. The classification product was analyzed at regional scales to compare distributions of existing and possible tree canopy spatially and create a baseline to track changes in the future.

Sample Land Cover Changes: 2000-2014

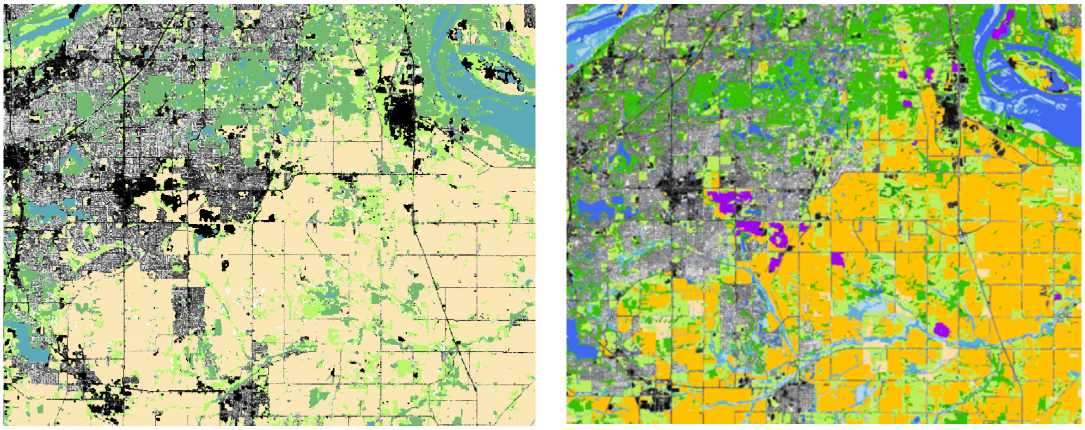
Conservation and management of Minnesota's natural resources require significant investments of time and money by many state/local agencies and stakeholder groups. Success in such efforts necessarily begins with accurate quantification of land cover. Yet land cover change is a constant process across Minnesota. The previous statewide land cover data (2000) did not include the effects of the boom growth period, changes in agricultural production, or changing forests. The figures below show examples of some of the many anthropogenic changes in land cover in Minnesota between the previous 2000 classification and this new 2013-14 dataset.



Extensive urbanization in Woodbury, MN (center frame) from 2000 (left image) to 2014 (right image) is an example of the significant development occurring in the Twin Cities Metropolitan Area and other cities in Minnesota. Urban areas appear as gray and black.

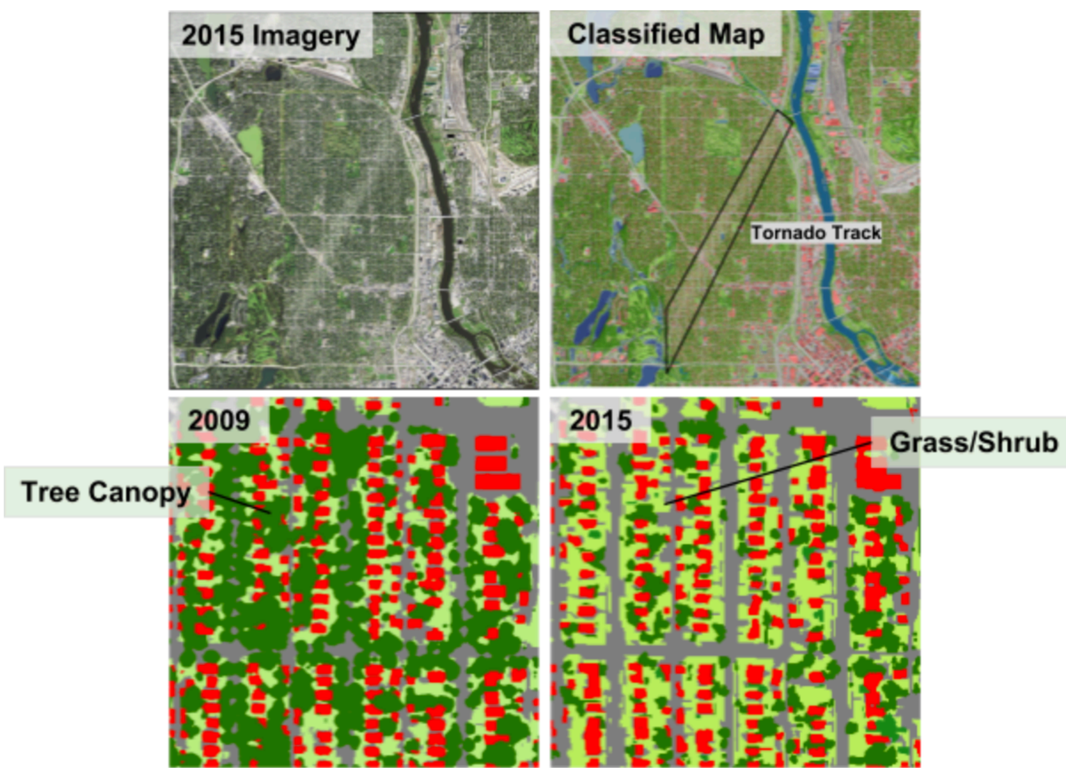


The effects of the 2011 Pagami Creek fire in the Boundary Waters Canoe Area Wilderness (center and center-bottom). In the 2000 classification, the burned area is classified as forest. In the 2014 image on the right, the same area appears as shrubby vegetation (light blue and light green).



Increasing extraction from the large quarry in Apple Valley. The 2000 classification (left) shows the quarry as black shapes just left of center. In the 2014 classification (right) the quarry has expanded significantly and is shown in purple.

Natural activities also cause land cover changes. On May 22, 2011, a devastating tornado swept through the northern portion of the city of Minneapolis. The National Weather Service ranked the strength of the tornado as an EF1 tornado with winds between 86 to 110 miles per hour.[1] In addition to extensive property damage, many urban trees were lost. From the 2015 optical imagery, a straight swath is a visible scar on the landscape where the tornado was in contact with the surface (figure below). By isolating this track and comparing before-after tree canopy assessments, it was found that 150 acres of tree canopy was lost. Paved surfaces or grass/shrub classes increased to account for most of the lost tree canopy.



Tornado track visible in 2015 imagery due to differences with surrounding tree canopy.

[1] http://www.dnr.state.mn.us/climate/journal/tornado_110523.html

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Appendix

Error Matrix by area

Duluth						
	Reference					
Classified	Developed	Extraction	Tree Canopy	Grass/Shrub	Total	**User's**
Developed	57	0	1	0	58	**98.30%**
Extraction	0	1	0	0	1	**100.00%**
Tree Canopy	2	0	142	14	158	**89.90%**
Grass/Shrub	11	0	4	63	78	**80.80%**
Totals	70	1	147	77	295	
Producer's	**81.40%**	**100.00%**	**96.60%**	**81.80%**		

Overall	89%
95% CI	86% – 93%
Kappa	0.824
Kappa Variance	0.000844
Kappa Z-stat	28.375

TCMA							
	Reference						
Classified	Developed	Extraction	Tree Canopy	Grass/Shrub	Agriculture	Total	**User's**
Developed	288	4	1	13	0	306	**94.1%**
Extraction	0	11	0	0	0	11	**100.0%**
Tree Canopy	15	0	275	26	1	317	**86.8%**
Grass/Shrub	23	0	17	178	10	228	**78.1%**
Agriculture	1	0	1	18	215	235	**91.5%**
Totals	327	15	294	235	226	1,097	
Producer's	**88.1%**	**73.3%**	**93.5%**	**75.7%**	**95.1%**		

Overall	88%
95% CI	81 - 89
Kappa	0.76
Kappa Variance	0.001042
Kappa Z-stat	23.549

Rochester							
	Reference						
Classified	Developed	Extraction	Tree Canopy	Grass/Shrub	Agriculture	Total	**User's**
Developed	53	0	0	2	0	55	**96.40%**
Extraction	0	2	0	0	0	2	**100.00%**
Tree Canopy	2	0	36	2	0	40	**90.00%**
Grass/Shrub	1	0	0	40	1	42	**95.20%**
Agriculture	0	0	0	2	14	16	**87.50%**
Totals	56	2	36	46	15	155	
Producer's	**94.60%**	**100.00%**	**100.00%**	**87.00%**	**93.30%**		

Overall	94%
95% CI	90% – 98%
Kappa	0.911
Kappa Variance	0.000746
Kappa Z-stat	33.336