Minnesota Lidar Plan

October 2021

3D Geomatics Committee
Data Acquisition Workgroup

MINNESOTA
GEOSPATIAL ADVISORY COUNCIL

Executive Summary

This plan outlines the need for a new lidar collection in Minnesota, and the path to acquire and support it. Minnesota was an early adopter and national leader for statewide lidar technology before USGS standards were in place. Lidar technology is used to measure geographic features. Lidar data has a wide range of uses and applications, including hydrographic modelling, geologic and mineral resource assessment, infrastructure and construction management, and forest resource assessment.

However, our current data is more than 10 years old, and no longer meets the Minnesota's expanded business needs that require much higher data quality. Additionally, over the last decade Minnesota's landscape has experienced significant natural and anthropogenic changes that are not reflected in these data, including floods, blowdown, fire, terrestrial invasive species, and substantial urban and rural development.

The Minnesota Lidar Plan is designed to be a living framework as the statewide work evolves over the next five years and beyond. Minnesota's goal is to exceed current USGS standards, and to provide more accurate data (higher densities) for more sectors than the previous statewide lidar data allowed.

High-level objectives are to: provide a guide to acquire enhanced and updated statewide high density airborne lidar and derived products; educate stakeholders about the benefits of improved lidar for Minnesota; generate inclusive, collaborative opportunities for data users and practitioners; and make these data supported, and publicly available by the end of 2025.

The Minnesota Geospatial Advisory Council's 3D Geomatics Committee (3DGeo) and the Minnesota Geospatial Information Office (MnGeo) are partnering on this plan. They have identified mission-critical stakeholders, and end user business needs. Key components of the plan include a list of lidar-derived products, specifications, and estimated costs, and recommendations to acquire, store, and serve these data to state and local government, private and nonprofit organizations, and the general public. The plan also touches on current national efforts to create a nationwide elevation dataset led by the United States Geological Survey (USGS) 3D Elevation program, 3DEP. A series of maps illustrate benefits from simultaneous lidar data collection, based on factors such as similarities in landscape, watershed, and political boundaries.

We have included baseline information for a host of disciplines and applications, including: improved mapping for transportation and infrastructure assets, wildlife habitats, micro drainage, and precision agriculture and hydrologic terrain modeling; more accurate ground level windspeed forecasting for windfarms, solar panel suitability, forest biomass (structure) analyses and inventory, and archeological resources assessment.

Finally, the plan highlights opportunities, and the return on investment for Minnesota that will be gained from enhanced, improved high resolution elevation data. Enhanced and updated statewide high density airborne lidar is essential to meet Minnesota's current and future business needs.

Contents

Introduction

This plan is a tool to facilitate the acquisition of the new lidar data, the creation of derivative products and distribution of the data, educational outreach, and support for an ongoing and evolving process that will take several years. To reflect the dynamic nature of the effort, this plan will be a living document, with updates as factors change, such as technology, areas of interest, costs, partner availability and other considerations. The history of the document versions is noted in the Document History of this plan.

MN Geospatial Community Partners

The creation of this plan and its implementation is guided by the partnership of the Minnesota Geospatial Advisory Council's 3D Geomatics Committee, the National States Geographic Information Council, and Minnesota's Geospatial Information Office (MnGeo).

The Minnesota Geospatial Advisory Council (GAC) is a twenty-three-member council that acts as a coordinating body for the Minnesota geospatial community. It represents a cross-section of organizations that includes counties, cities, universities, businesses, nonprofit organizations, federal and state agencies, tribal government, and other stakeholder groups that benefit from geospatial technology. The GAC sets priorities yearly, and committees and workgroups lead the effort to work towards those priorities. The GAC 3D Geomatics Committee (3DGeo) works to identify and promote the need for planning, funding, acquisition, and management of three-dimensional geomatic data and derived products.

The 3DGeo Committee is organized by workgroup sectors; each sector has members with specialization in GIS, remote sensing, and lidar technologies. Workgroups are comprised of data stewards, data developers, and users of lidar-derived products who have close working relationships with end users. These associations with users, coupled with hands-on knowledge on lidar-derived products, makes them ideally situated for providing guidance in lidar acquisition across Minnesota and ensuring that 3D point cloud and derived products are widely accessible and meet user expectations and business needs.

National States Geographic Information Council (NSGIC) has a project, 3DEP for the Nation, that is conducted in cooperation with the USGS National Map 3D Elevation Program and the Federal Geographic Data Committee (FGDC) 3DEP Working Group. Minnesota is one of the NSGIC's second set of pilot states. This plan has benefited from NSGIC's work, specifically, the 3DEP Lidar Acquisition Planning Guide developed to guide State lidar plans.

The Minnesota Geospatial Information Office, known as MnGeo, was established in May 2009 as the first state agency with legislatively defined responsibility for coordinating GIS within Minnesota. Guided by state agencies, other government and non-government stakeholders through the GAC, its coordination activities focus on six core activities including community outreach, communications, geospatial data and technology coordination, data and web services, training and technical guidance.

This Plan and its implementation are led by the 3DGeo Data Acquisition Workgroup and MnGeo. Many were involved with the creation of this plan and are listed in Appendix: Minnesota State Lidar Plan Team Members.

Partnership with Minnesota Tribes

Partnership between the Minnesota Tribal Nations and the 3DGeo Data Acquisition Workgroup and MNIT MnGeo is essential to the work to plan for, acquire, store and distribute new lidar data. Minnesota IT Services looks forward to engaging and collaborating with Tribal Nations about next steps for lidar acquisition.

Plan Objectives

This Minnesota Lidar Plan has several objectives. One objective is to document and communicate the need for, and value of new and higher quality lidar data in Minnesota. Another objective is to provide proposed geographic lidar collection areas. This document identifies cost estimates for lidar acquisition, derivative data product creation and ongoing storage and distribution. The plan includes a summary of how the lidar acquisition efforts and status will be communicated to the broader GIS community to ensure their involvement and understanding of the effort.

In addition to the Minnesota-focused objectives, this plan is intended to be a communication tool with Federal partners, including the U.S. Geological Survey (USGS), National Resources Conservation Service (NRCS), Federal Emergency Management Administration (FEMA), National Oceanic and Atmospheric Administration and other federal partners and stakeholders about Minnesota’s contributions towards the goal of a nationwide baseline of consistent high-resolution elevation data.

To provide context for the future of lidar in Minnesota, the following background section explains the technology and past lidar collections.

Background

Understanding Lidar

Three-dimensional (3D) mapping of earth's surface and the vertical structure of objects on its landscape (e.g., buildings and trees) are essential to a broad range of applications for resource management and decision making. Although some of this technology has been around for decades, modern 3D elevation data is acquired using highly sophisticated instrumentation mounted on small aircraft to map earth's surface, capturing all natural and human built features on the landscape with incredible speed and precision. Surfaces reflect the light back to the system sensors where it is analyzed to capture both the return time of travel from the surface and the intensity of the light pulse. The recorded time it takes for the light to return provides a measure of range (i.e., distance) to the target surface. The result is a cloud of points, otherwise known as a "point cloud" with precise X, Y, and Z location for hundreds of millions of points in a single small area.

A Digital Tape Measure

Think of this technology as a virtual tape measure with the beam of light as the tape. This is the same science used by hand-held devices (i.e., laser range finder) commonly utilized in golfing, hunting, and construction to measure distance. In a lidar system, the light pulses combine with high accuracy global positioning systems (GPS) and inertial measurement units to determine the exact location of the source equipment and the resulting target surfaces. Each retrieved segment of a pulse creates a point defined by real-world coordinates and elevation (i.e., X, Y, and Z). Lidar sensors collect millions of these points in a short amount of time, where collectively, they form a "point cloud" of data, which produces a 3D rendering of all the surfaces encountered by the laser pulses. The point cloud, the accuracy of the measured locations, and the density of those returns are described as having different Quality Levels (QL), where QL0 has the highest accuracy and density and QL3 has the lowest (Table 1).

Quality Level	Nominal Pulse Spacing (m)	Nominal Pulse Density (pulse per square meter)
QL0	≤0.35	≥8.0
QL1	≤0.35	≥8.0
QL2	≤0.71	≥2.0
QL3	≤1.41	≥0.5

Table 1: Nominal pulse spacing and pulse density (source: USGS Lidar Base Specifications v. 2.1).

Imagine your dining table; without knowing its size, or the number of chairs around it, you really don't know how many people can be seated there. It is likely that your table is about 2 square meters in size. In a QL3 lidar collect (as in what is available in the current statewide lidar dataset) you would have only about 1-2 lidar returns in the point cloud, making it very difficult to describe the size of your table with this data. In a QL2 lidar collect you would have about 4-8 points to work with and thus you will have a better idea of the size of the table, that there are items on the table, and you could possibly pick out some of the chairs. Adding even more points to your estimate using QL1 or QL0 lidar data (16-32 points), and you may be able to more closely resolve the size as well as shape of the table, what's served for dinner, and even count the number of chairs. To conclude this analogy, some people care about the table, some about the chairs, and some only need to know whether it's in a dining room. To strike the balance, we need to consider as many common business needs as possible, and strive to acquire the QL that is necessary to address them.

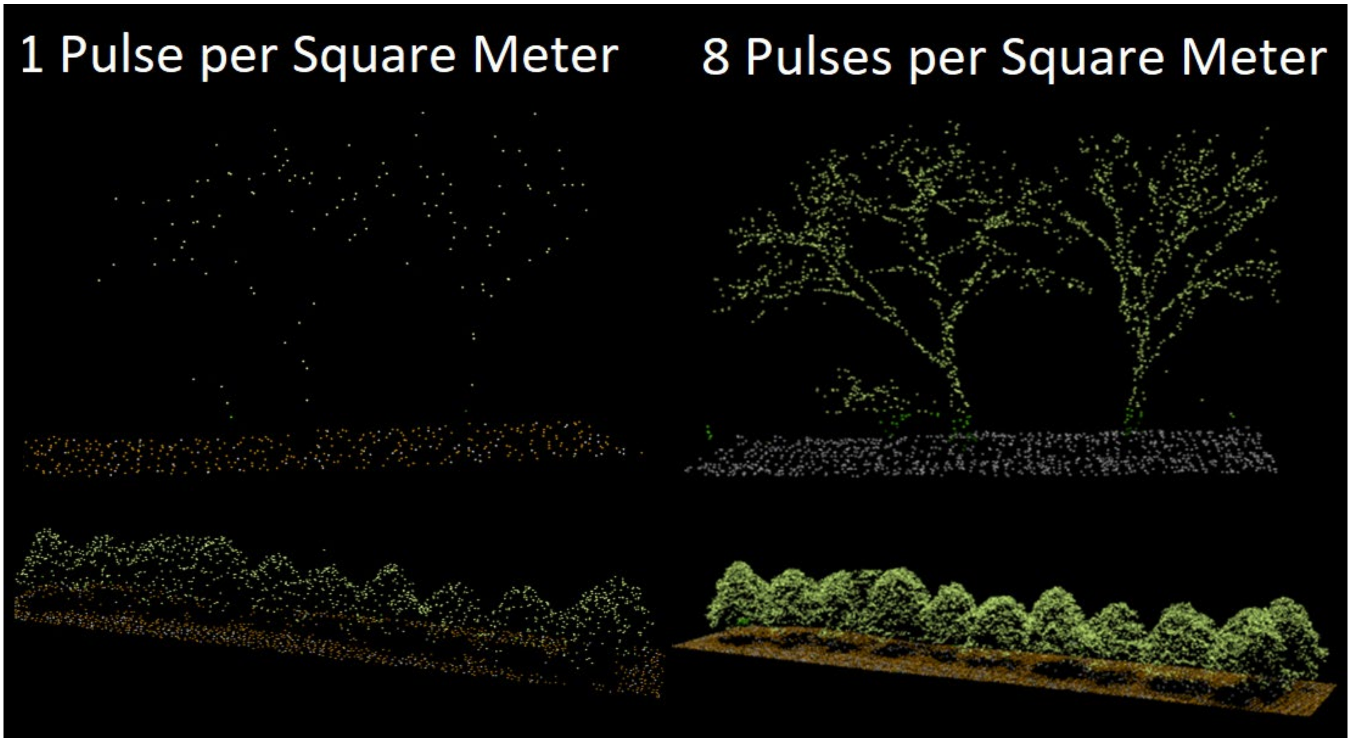

Figure 1: Illustration showing two different forested areas, deciduous (top) and coniferous (bottom) at two different lidar pulse densities. The left image represents a low lidar pulse density (QL3, 1 pulse per square meter) resulting in less lidar points and less feature definition. The right image shows the details gained from a high pulse density (QL1, 8 pulses per square meter) resulting in a high density of points and highly detailed feature definition.

> Each retrieved segment of a pulse creates a point defined by real-world coordinates and elevation (i.e., X, Y, and Z).

Minnesota's Current Lidar Data

Minnesota is fortunate to have a rich history of collection geospatial data and a solid background in acquiring lidar data guided by input from the user community. Lidar acquisition plans for various states across the nation have demonstrated success when guided by subject matter experts and stakeholders. These committee-based approaches assure end users that the lidar derived products serve the greatest amount of business needs while maximizing the use of public tax dollars by ensuring specifications are met and that the largest footprints of acquisition are achieved to bring costs down.

First-Generation Lidar

A committee of stakeholders across Minnesota united to form the Digital Elevation Committee. This group managed Minnesota's initial lidar acquisition under the Minnesota Elevation Mapping Project. The goal of that project was to develop and deliver a seamless digital elevation map of the state of Minnesota, based on data collected using lidar technology. Starting in 2007, this initiative guided lidar procurement projects until the state was blanketed with lidar data in 2012. Although Minnesota's first generation lidar data was state of the art at the time of procurement, and one of the first available statewide lidar datasets in the nation, less than one lidar-elevation point per square meter was collected (0.6 points/square meter) and during leaf-off conditions. As a result, the data now classifies as QL3 lidar data, the lowest quality of lidar, and does not meet the nation's current standards for high quality elevation data.

Changes to the Landscape

Although incredibly detailed compared to traditional topographic maps, a lidar data collection event is still a snapshot in time of a surface. Unfortunately, much of Minnesota's first generation lidar data is nearly a decade old, and not able to provide a reasonably current depiction of the landscape. Heavy rain events, flooding, forest fires new land use management practices, development and modification of societal infrastructure (e.g., road and utility), and new construction in response to Minnesota's strong economy, have fundamentally changed the landscape. That means all foundational end-user data products derived from Minnesota's first generation lidar data are now out of date. As a result, the aging status and poor quality of these data fail to meet an ever-growing amount of elevation-dependent business needs, such as hydrologic modeling, asset management, and forest canopy mapping. In addition to these landscape changes, nearly a decade of technological advancements has occurred making new enhanced lidar acquisition an attractive, and essential investment for Minnesota.

USGS 3D Elevation Program (3DEP)

The interest in new improved quality lidar is not limited to Minnesota. The U.S. Geological Survey (USGS) is working towards the goal of a nationwide baseline of consistent high-resolution elevation data by 2023. There is significant interest in Minnesota by many federal, state and local stakeholders as the currently available elevation data in Minnesota is nearing 10 years old in most areas and in nearly every case does not meet federal agency standards of resolution or accuracy.

The USGS is leading this nationwide elevation effort through the 3D Elevation Program (3DEP). The National Geospatial Program 3DEP is systematically guiding the collection of 3D elevation data in the form of lidar data for the United States, and the U.S. territories. USGS and other federal partners are granting funding support in the collection of lidar if it meets minimum quality requirements. 3DEP is based on the results of the National Enhanced Elevation Assessment (NEEA, 2011) that documented more than 600 business uses across 34 Federal agencies, all 50 States, selected local government and Tribal offices, and private and nonprofit organizations. The top 10 benefits included flood risk management, infrastructure and construction management, natural resources conservation, agriculture and precision farming, and water supply and quality, and wildfire management planning and response. The NEEA concluded that publicly available, nationwide lidar elevation data would provide more than $690 million annually in new benefits to government entities, the private sector, and citizens. This is enormous and nearly a 5:1 return on investment informing critical decisions that are made across our Nation every day that depend on quality elevation data, ranging from immediate safety of life, property, and environment to long term planning for landscape and infrastructure projects. (See Fact Sheet (PDF), 2012)

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The Broad Agency Announcement is the grant coordinating mechanism for 3DEP. It guides partnerships between the U.S. Geological Survey (USGS), other Federal agencies, and other public and private entities seeking to collaboratively invest in high-quality 3D lidar Elevation data acquisitions.

- Federal agencies, state and local governments, tribes, academic institutions and the private sector are eligible to submit proposals through the BAA process
- Applicants may contribute funds toward a USGS lidar data acquisition activity or they may request 3DEP funds toward a lidar data acquisition activity where the requesting partner is the acquiring authority

Working collaboratively to apply for USGS 3DEP grant funds is key to the success of both the Minnesota Lidar Plan and the overall goals of USGS. As this Plan is put into action and evolves, one of the shared tasks for partners is to express their interests by adding their geographical areas of interest (AOIs) for lidar collection into a common map interface. The USGS relies heavily on the overlapping AOIs in a given area to weigh their decision on whether to move forward with a BAA and assist via the 3DEP grant. The tool that is used to collect AOIs nationwide is called SeaSketch.

Nationwide Coordination of Acquisition using SeaSketch

Areas of interest for lidar acquisition are submitted to an online using SeaSketch. Partners can see the overlapping areas for potential collaboration and so the USGS can see these mutual interests in order to judge applications to the 3DEP BAA. SeaSketch is an online spatial mapping platform developed by the Marine Science Institute at the University of California Santa Barbara. This USGS 3DEP SeaSketch platform was designed to be customized to allow different 3DEP stakeholders to use it for planning and monitoring through an interactive web map. The Integrated Working Group on Ocean and Coastal Mapping (IWG-OCM) and the USGS 3DEP are using SeaSketch to coordinate preliminary lidar acquisition plans of Federal agencies with partners around the country. Leveraging partnerships in this collaborative mapping platform eliminates redundant efforts and helps coordinate funding, schedules, priorities, specifications, and sensors to ensure the acquisition of lidar data serves the greatest amount of business needs.

The readers of this Plan are highly encouraged to submit their AOIs to get their business needs heard and to improve the competitiveness of all of Minnesota's upcoming 3DEP proposals. If you are interested in uploading an area of interest, for the online help in the 3DEP SeaSketch provides help, and 3DGeo has prepared an SeaSketch Areas of Interest Instructional Handout that provides instructions,

Value and Benefit of New Lidar to the Minnesota

Minnesota is nearly 87,000 square miles in size and is located at the confluence of three major ecological regions: the Northern Forests, Eastern Temperate Forests, and the Great Plains. Minnesota is the metaphorical heart of the North American continent's surface freshwater supply, with more than five major river basins, including the Mississippi River, Red River, Rainy River, Lake Superior, and Minnesota River. The Headwaters of the Mississippi River and the Mississippi River basin are in the center of the state, and supply drinking water for millions of people downstream. The Minnesota River flows almost entirely within the state and drains to the

Mississippi River. There is even a small portion of the Missouri River Basin within Minnesota, which ultimately drains to the Mississippi outside state boundaries. These basins form part of a drainage area that covers more than 40% of the Nation. The Red River of the North forms the western boundary with North Dakota, and the Rainy River forms part of the northern border; these rivers flow into Canada and ultimately to Hudson Bay. Lake Superior, the largest freshwater lake by surface area on Earth, is part of the Great Lakes Basin which contains 20% of the world's freshwater supply.

The State of Minnesota is known as "The Land of 10,000 Lakes" and elevation data has been vital in managing water and natural resources in the state. Over the last 12-14 years, several counties and project areas have acquired lidar data to support several mapping requirements. Over time, a growing and broad range of applications have been realized with these lidar data, despite the lower quality and aging of most existing data, including: assessment of solar insolation suitability, forest resources assessment, wildlife habitat management, precision farming, conservation and restoration prioritization, flood risk management, infrastructure and construction management, water supply and quality, coastal zone management, geologic and mineral resources assessment, and many other business uses.

While the existing lidar data and DEMs may be moderately accurate in most areas, they still only represent a snapshot in time on a landscape that has largely experienced intense change over time. Natural resources such as soils, forests, rivers, lakes, and wetlands are dynamic features that are highly dependent on both large to small geographic and time scales, influenced by local to landscape scale land use practices, and conditional to both weather and climatic factors that need monitoring and mitigation. Best management practices to mitigate these challenges rely on highly accurate elevation data (both in terms of relative age of the data and positional accuracy). With the appropriately representative elevation dataset, tactical efforts are more effective in reducing nutrient and sediment loading, mitigating and respond to floods, and effectively providing cost avoidance structures to prepare for natural disasters. These efforts require maintenance in baseline elevation data at resolutions, both temporal and spatial, that are not available with the current era digital elevation data.

The following section is meant to evolve over future iterations of this Plan document, with the goal to cumulatively and collaboratively highlight example use cases, their potential return on investment, value, and/or benefit (though it may be difficult to quantify at times), and ultimately explain why having new higher density and higher quality elevation data is necessary for Minnesota.

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Hydrologic Resources

Minnesota is fortunate to have an abundance of clean, clear water. Our communities have been designed by and have evolved from the benefits and transit capabilities of our waters; many of us still define our lives around the waters in this state. Placing a high value on these water resources, the citizens of Minnesota voted to establish the Clean Water, Land, and Legacy Amendment in 2008. As a result, a portion of the state's sales tax is dedicated to the Clean Water Fund, which supports projects and products that protect, preserve and improve the water quality of Minnesota.

Most, if not all, of these projects require detailed and accurate information that describes the lay of the land. The morphology of the landscape defines how precipitation transforms into flowing water, and subsequently that flowing water shapes the landscape. Detailed topographic information is essential to understanding this dynamic process and best mitigate the human influences on the hydrologic systems of earth, like nutrient and sediment loading due to intensive land use practices. To meet this need, a portion of the Clean Water Fund was used to complete Minnesota's initial statewide lidar coverage. This funding was also was used to compile the state's first detailed elevation dataset, otherwise known as a Digital Elevation Model (DEM), from low density lidar in a consistent format for the entire state and to make both the lidar derived DEM and other related products readily available without charge to the public.

Figure 1 below illustrates the use of lidar-derived products for use in landscape planning and hydro-terrain analysis work for use in Best Management Practice (BMP) placement. The red-yellow-black basemap is the lidar DEM-derived Hydrographic Position Index (HPI) representation of landscape topography with lidar-derived flow paths (blue) draped on top. Landscape ecology and hydrology models use this information for strategic placement of best management practices that strive to improve the water quality of Minnesota (white = terraces, green = impoundment structure, purple = impoundment basin). Note: The purple is the ponded area of the impoundment structure. There is a separate layer that defines the watershed for the impoundment, or WASCOB's (Water and Sediment Control Basins).

With updated elevation information at higher densities than previously available, vast time savings would be gained. One example of time savings with higher quality and more up to date elevation datasets is the identification of digital dams and water conveyance structures is much easier. Being able to accurately route the digital flow of water across the landscape is mission critical for a mired of applications. Collectively, high density lidar provides a 3D topographic representation and paints a much more accurate hydrologic scene for our minds eye that shows how water movement shapes Earth's surface.

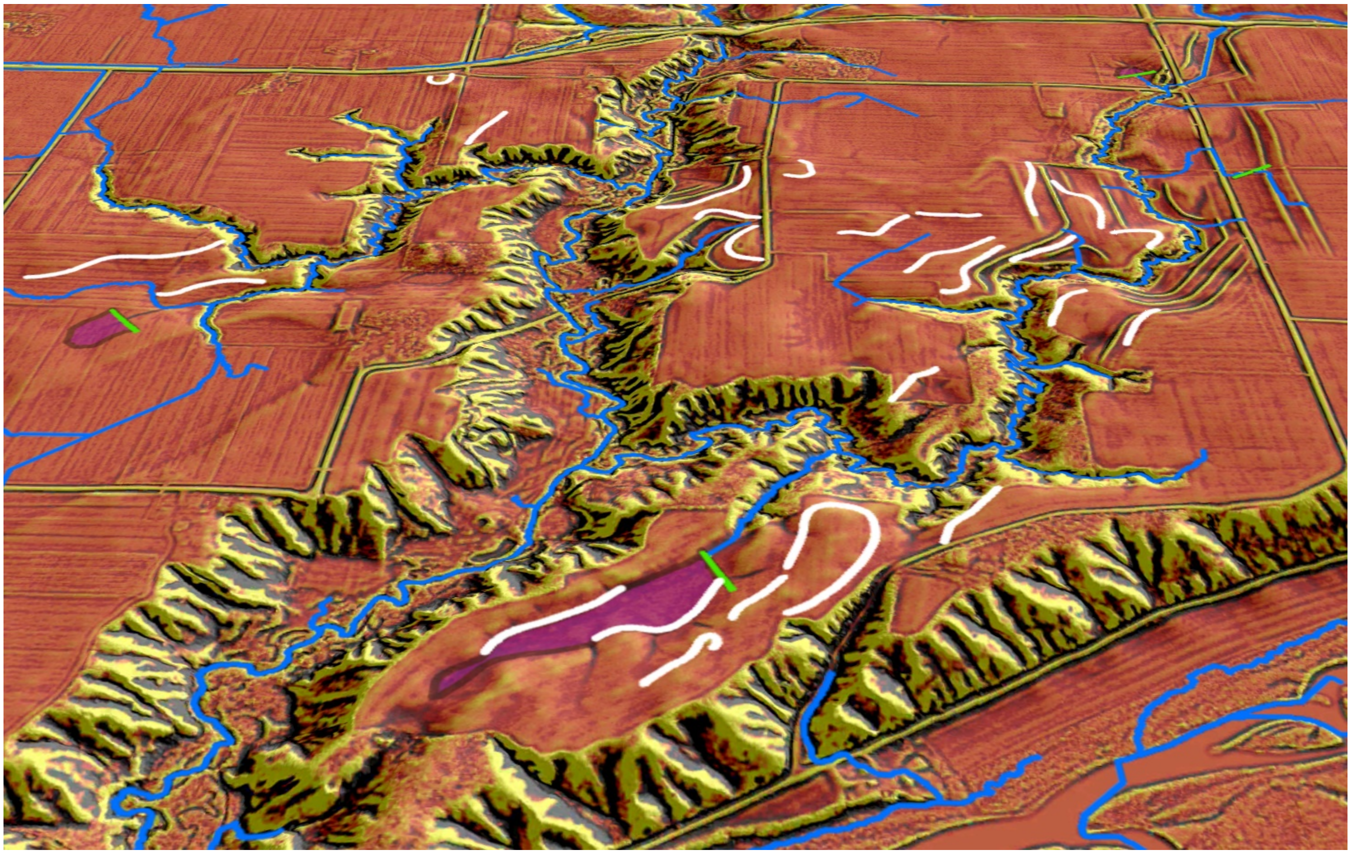


Figure 2: Lidar derived DEM-derived Hydrographic Position Index (HPI) representation of landscape topography with lidar-derived flow paths (blue) draped on top.

Geology, Groundwater, and Mineral Resources Applications

Minnesota land-surface geology largely consists of relatively young Ice Age sediments over most of the state, with complex ornamentation mostly related to glacial processes. Older glacial sediments with subtler topography occur in the southwest and southeast. Along the Minnesota River Valley, as well as in the southwest, southeast, and northeast, underlying rocks are exposed. Geologists use remote sensing technologies to study the subsurface, including magnetic, gravitational, and seismic surveys, which supplement information from water well installation records and other drilling.

Despite our abundance of lakes and rivers, our principal source of drinking water statewide is groundwater from wells. Geological mapping is crucial to understanding how water flows and is stored and ultimately to support tactical and life-dependent groundwater protection and proper infrastructural management in Minnesota. In addition, geological mapping supports engineering, assessment of landslide and sinkhole risk, and existing and potential mining, especially for the sand, gravel, and crushed stone that is needed for construction of roads and building in every county.

Geologists seek to map the subsurface with limited methods that look deep into the ground. Thankfully, land surface features are one of the most important clues geologists can use to interpret geology. Detailed data is needed to differentiate thick sediment from exposed rock, and in the case of both sediments and rocks, to infer the material properties and geometry of what is in the shallow subsurface, for strata that are influencing land surface geometry.

For these reasons, lidar has superseded most less effective methods of the past. It has become one of the most powerful tools that geologists can use. Higher resolution/higher quality lidar would bring many benefits for geological mapping in the state. Landslides and sinkholes would be more clearly defined. Sediment features such as boulders, eskers, dunes, and glacial lake shorelines would be better resolved. In areas of exposed rock, newer and high density lidar would dramatically improve insights into the structure and character of exposed rocks, resulting in yet another revolution in the impact and efficiency of these investigations. In addition, misidentification of exposed rocks would be reduced, resulting in more efficient utilization of time in the field.

The benefit of having higher quality and updated digital elevation data include the potential avoidance of construction in sensitive surface or groundwater influenced areas, which could ultimately save vast amounts of clean up dollars and health repercussions for the state.

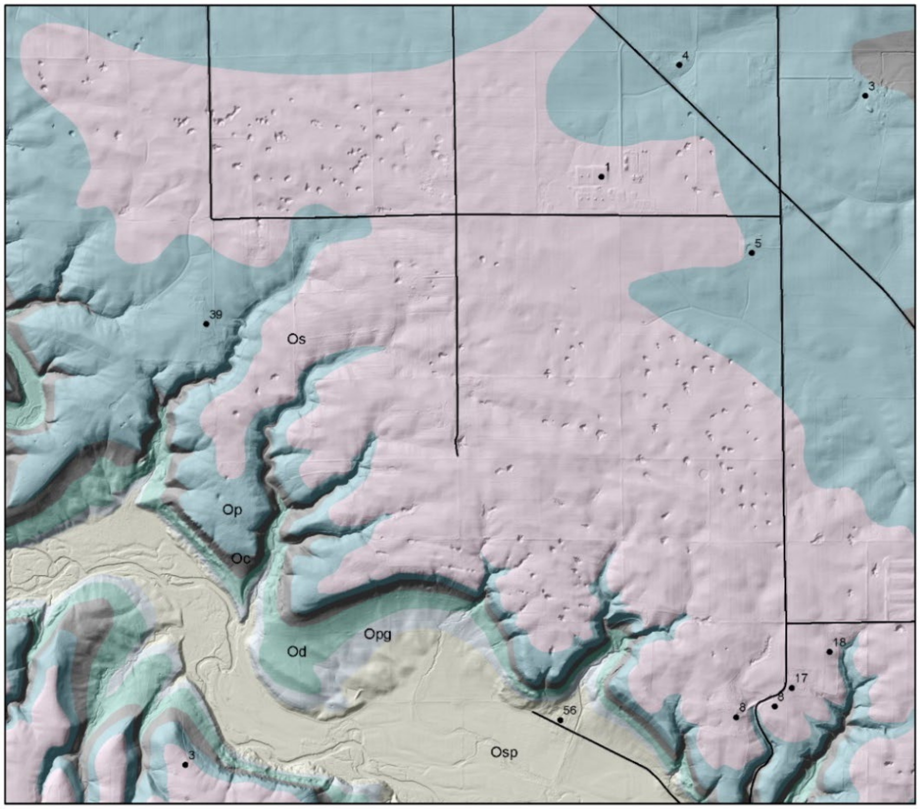


Figure 3: Portion of Olmsted County with geological mapping superimposed on a lidar-based digital elevation model (DEM). Sinkholes are apparent as small pits, and preferentially occur within the Stewartville Formation, labelled with “Os” . Black dots show water wells with depth to bedrock in feet.

Infrastructure and Construction Management

Aerial imagery and photogrammetry have been relied on for high accuracy survey for the Minnesota Department of Transportation (MnDOT) for over 40 years. However, these data have their limitations. For example, it can be difficult to map the bare Earth in dense coniferous areas found in much of Northern Minnesota. In these areas, traditional ground-based survey is needed to fill in the voids left after the photogrammetric process or with low density lidar, making the work very time consuming and labor intensive due to the high amount of accuracy required.

Today’s lidar sensor technology and the capability of very high-density scanning enables small fractions of the laser pulses to shoot through gaps in the forest canopy and reach the bare Earth below, allowing engineers to use lidar-derived models to perform analyses of areas from the office, thereby reducing field time and safety risks. For example, public utilities and MnDOT can accurately identify trees growing too close to utilities that need to be cleared. They can also be used to identify and avoid impacts on archaeological sites, calculate line of sight, determine the best location to build, accurately calculate cut and fill for road planning, identify heights of in-place assets, and overall identify and map streets, highways, railroads, grades, levees, buildings, and other man-made features with much greater detail and at a lower cost than ever before.

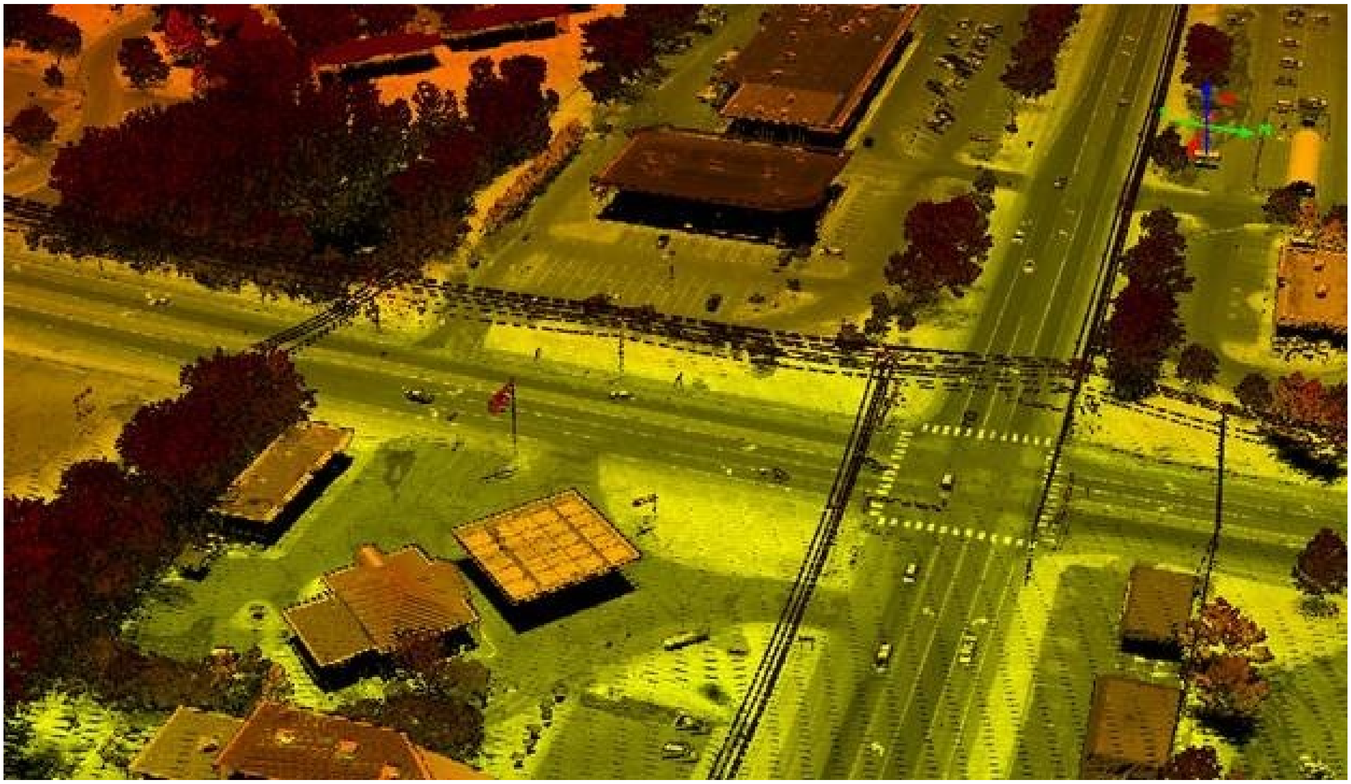


Figure 4: High resolution digital surface model of an area in the city of White Bear Lake, MN.

Forest Resources Assessment

Comprehensive forest inventory systems are a universal desire and utilized by many applications beyond wood fiber and lumber industry estimates, including for example wildfire risk assessment and foundational data for a host of other mitigation efforts in forest and habitat health monitoring. The costs of maintaining such a system with boots on the ground, especially considering the extensive and diverse nature of Minnesota's forest land base, continue to be a massive annual expense and long-term challenge ($1.5 Million dollars per year to maintain a 20+ year repeat internal).

Through a pilot project, the Minnesota Department of Natural Resources partnered with Cass County and the Chippewa and Superior National Forests to explore the accuracies achieved and cost savings gained with spatial forest inventory based on high density lidar (QL1) acquired across about a million acres of forested land during leaf on conditions in northern Minnesota. A complementary field campaign collected full stem forest inventory data in over 600 sample plots, measuring over 14,000 trees. Forest inventory metrics were modeled using numerous spatial predictors (combined forest type model, as well as broadleaf and conifer only models) and two sources of lidar data were tested: new high density lidar (QL1) and old low density lidar (QL3). Model results show higher accuracies for conifers compared to broadleaf for both sources of lidar data, and the combined models showed high density lidar performs significantly better.

Overall, the project results exposed the possibility of multiple benefits and a very large return on investment. Using high density lidar data for forest inventory can cut inventory costs by about 55% (this includes the cost of lidar and spatial analyses and is compared to the average annual cost of $1.5 million dollars for the same amount of acreage inventoried). It enables the analysis of valuable three-dimensional information across all lands not just state administered lands. Lidar derived forest inventory data becomes available much faster (as frequently as the data are collected and processed) than traditional field-based methods (where repeat intervals exceed 20 years). The data collected can be extended far beyond the narrow focus of forest inventory to benefit many more agencies, organizations, and stakeholder groups who are hungry for an affordable change to how forest inventory is conducted and are eager to use the value-added information provided by high density lidar.

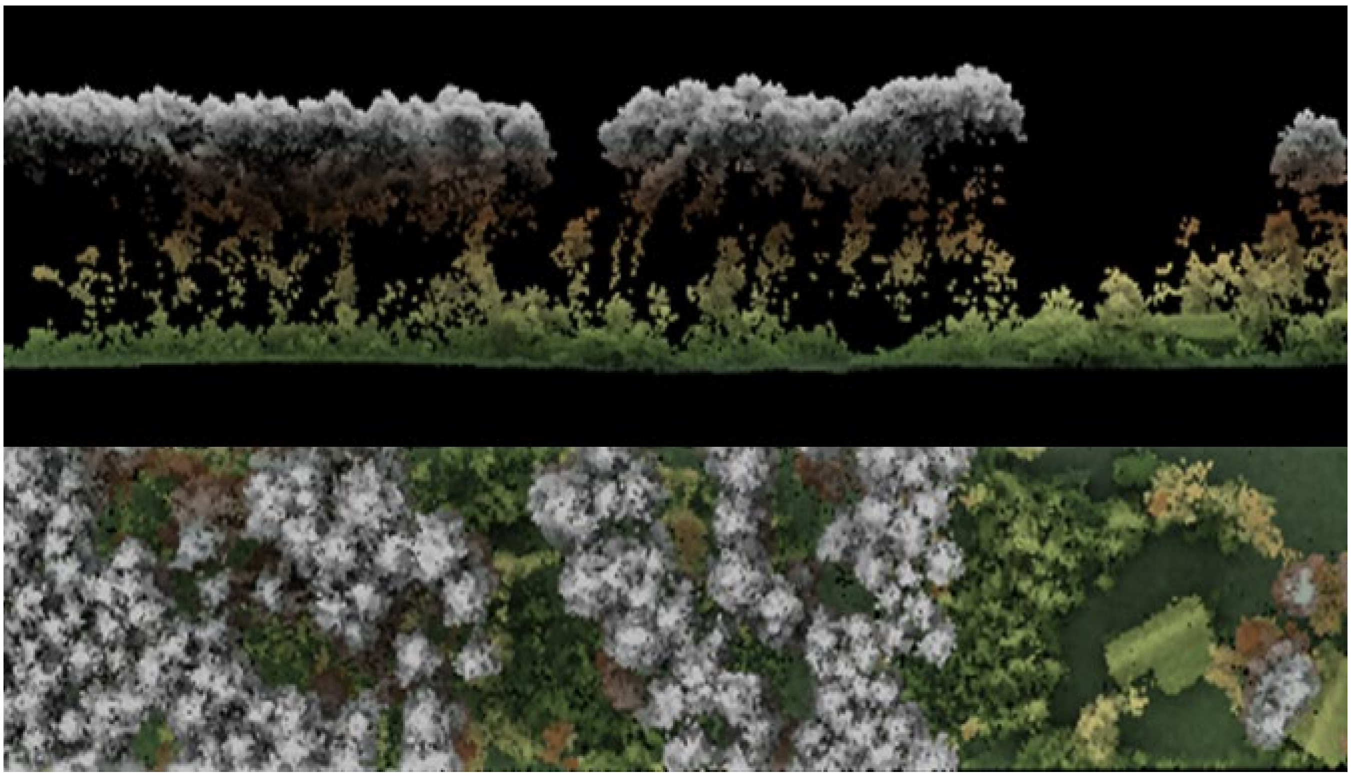
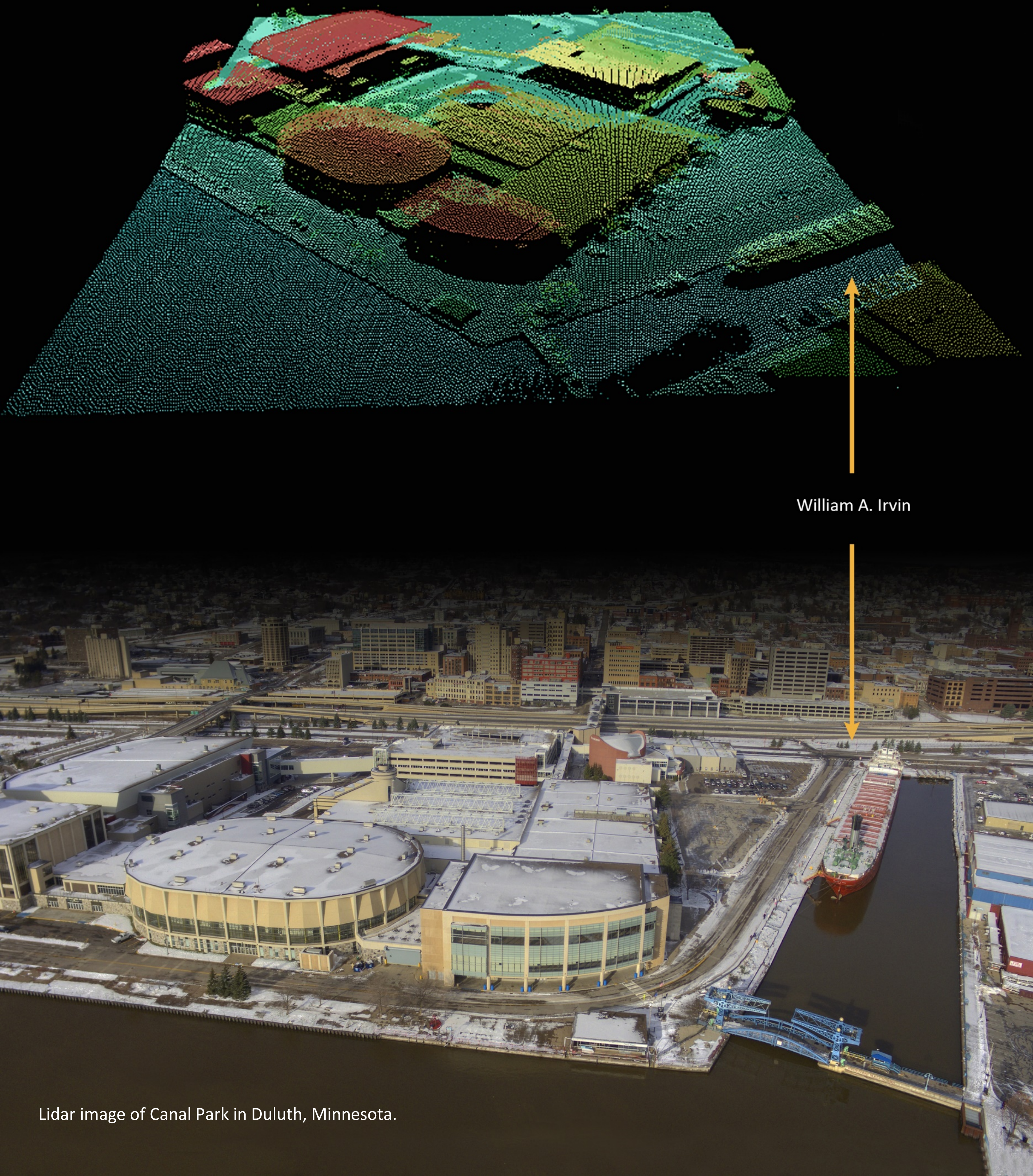


Figure 5: Lidar point cloud in an area of Cass County, Minnesota, collected in October 2017 (full leaf on, peak fall color). Top image depicts a cross section, colorized by height, and the bottom image is the overhead view of the same location.



Lidar image of Canal Park in Duluth, Minnesota.

Other Benefits of Lidar

Benefits may be difficult to quantify, including examples without direct associated costs or existing data histories to compare value. These benefits could be potentially larger than the tangible benefits. In fact, because we are still learning how to exploit 3D information for various non-traditional applications, it is more likely that we will never be able to fully define every possible value to having high density lidar and it will always be undervalued.

One example of benefits that are difficult to quantify is the MnDOT's use of lidar to reduce worker exposure to traffic and environmental hazards by limiting the amount of time workers need to be on the highways collecting data. By extension, the traveling public also benefits from decreases in lane closures and other temporary work zones created for ground survey workers. Utilizing lidar data allows for reduction in the number of necessary survey vehicles on the road, and resulting in lower carbon dioxide emissions involved in classic survey data collection. In addition, having high quality lidar data reduces the timeline from acquisition to final product and ultimately getting the data in the hands of decision makers. Often there is a long-time delay between data requested and data provided or there is need to create data by hand or from new ground survey data collection. In an emergency response such as a major inner-city flood, there is no time to create a spatial dataset of building footprints or map infrastructure on the scene at the time of incident. The repercussions of such invisible project delays can lead to not only cost overruns, but potentially could put many lives at risk. Though it may be difficult to pin down the exact dollar on cost avoidance or time savings for having high resolution lidar, it is undeniable that the return on investment has been vastly undervalued.

There are many ecosystem services and environmental related benefits that are also difficult to quantify. Decreasing the need for fieldwork in remote areas will reduce the safety risks in sending staff to remote areas that require traversing extensive, potentially dangerous, tracts of land. With lidar assisted models of forest inventory metrics, foresters and planners can prioritize where they concentrate their efforts and effectively streamline and increase the efficiencies of their fieldwork (both in terms of identifying which site to travel to and in terms of strategically getting to a specific spot within the selected site). Using high quality data that is collected across landscapes (i.e., wall-to-wall), habitat modeling and estimating the value of natural resources can transcend the politically defined boundaries and better mimic the patterns of wildlife movement. These improvements in mapping and modeling assist scientists and practitioners to maximize ecosystem service values and the investment that the public makes towards managing these resources.

Lidar Acquisition Areas of Interest and Potential Costs

Lidar and its derivatives have proven to be fundamental for natural and human resource management across these natural systems. Recognizing that local governments are vital for coordination of work and citizen representation; this Plan has attempted to strike a balance between natural and geopolitical boundaries by merging the boundaries of these major river basins with the political boundaries of counties into lidar acquisition areas (LAA) across Minnesota. Developed by the 3DGeo Committee, these LAAs serve as collaboration regions that strive to meet a diversity of stakeholder needs.

When taking these spatial boundaries into account, along with the need to ensure overlapping boundaries between disparate lidar acquisition areas over the course of the five-year Plan, the acquisitions effectively overlap a small amount. To accommodate lidar data collection in these regions, and to meet 3DEP requirements, we've overlaid the USGS defined 1 km x 1 km tiles. Knowing that terrestrial lidar collection from aerial platforms does not collect water surface or lake bottom elevations, these blocks excluded the vast open expanses of Minnesota's largest lakes. However, the shorelines of these lakes are included to ensure the lake--shoreline interface is accurately mapped. All other lake areas will be collected even if no data is generated because it is not feasible to avoid lakes or turn off lidar instruments during collection flights.

The following section outlines these proposed Lidar Acquisition Areas (LAA) with some regions broken down further into Lidar Acquisition Blocks (LAB). Described in the Cost Estimates and Funding Planning section found later in the Plan. Each of the proposed LAAs and LABs use the average cost estimates obtained from nine vendors to estimate the cost of acquisition per quality level. It should be noted that although the order in which these LABs are acquired has not been established officially, there are two LAAs that have many vested partners already: NE Forested and SE Driftless. Although there is established interest in some areas, all LAA/LABs need to fill significant gaps in funding.

Note that the square miles in the maps may not match the square miles in the summary tables because the statewide maps do the overlap of lidar acquisition areas that will be necessary when areas are collected at different times.

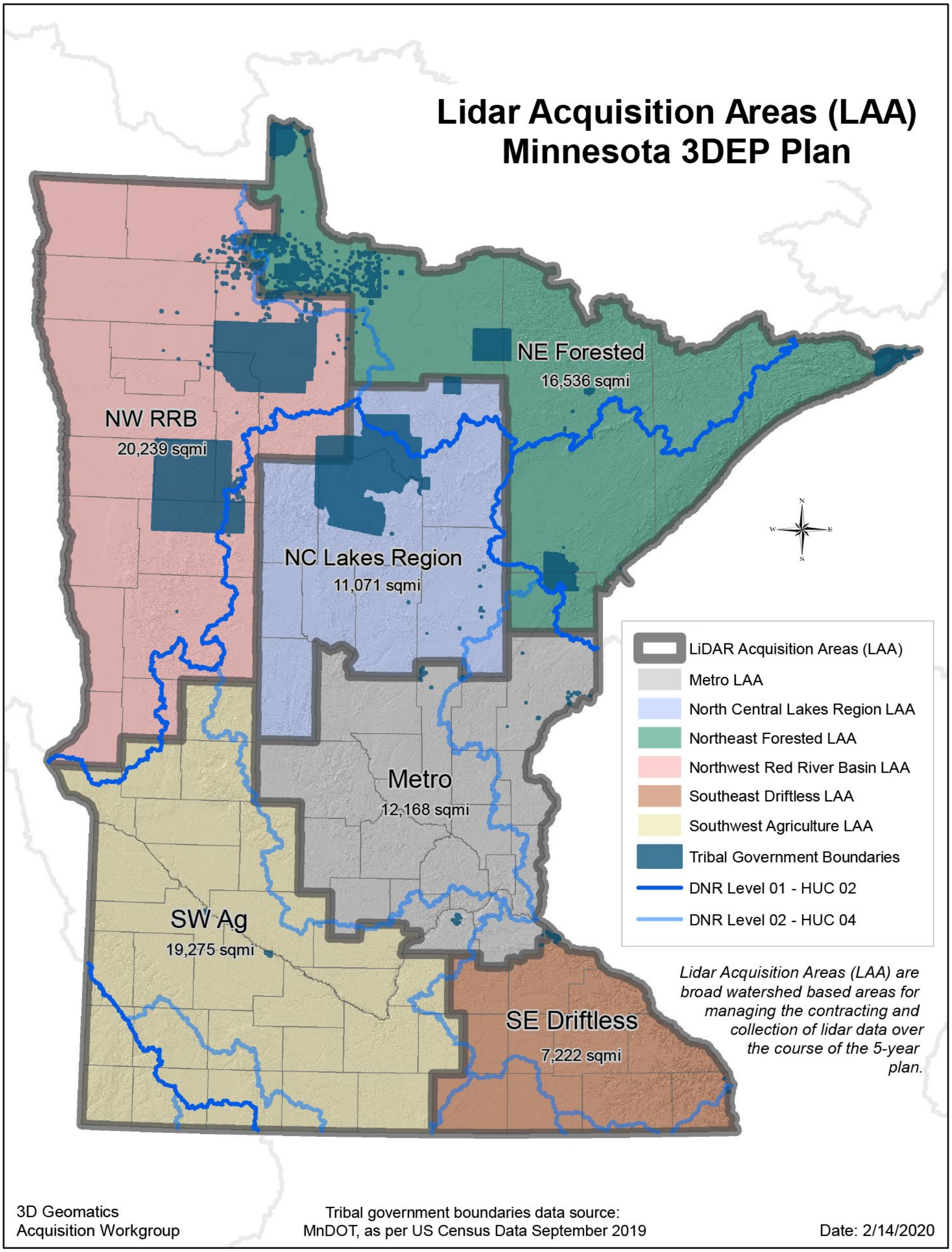


Figure 6: Map of proposed lidar acquisition areas (LAA), depicting broad watershed and political-based areas.

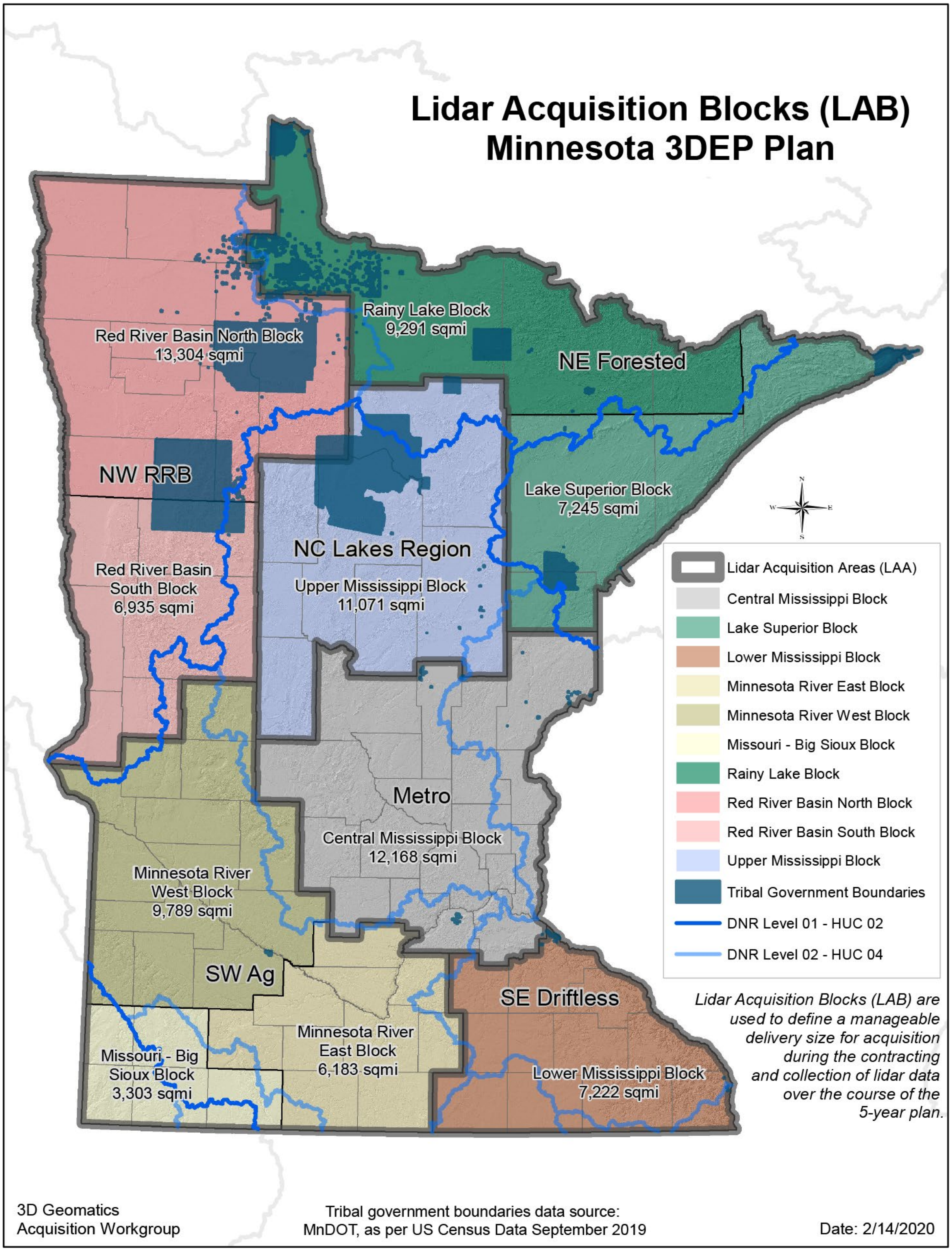


Figure 7: Map of proposed lidar acquisition blocks (LAB), depicting smaller acquisition blocks within the lidar acquisition areas (LAA).

Red River Basin Lidar Acquisition Area

The Red River Basin Lidar Acquisition Area (LAA) targets the 16 counties in the northwest part of the state covering 20,000 square miles. Moving from west to east, this LAA starts with flat low relief agriculture lands along the Red River and transitions to glacial moraines and lake basin topology in the west. This watershed based LAA drains primarily west and then north. The LAA has been divided into a north and south Lidar Acquisition Block (LAB) to maintain a manageable collection size. Estimated acquisition costs are as follows:

LAA/LAB	Quality Level 2 - 2 pulses m^2 (\$200/mi^2)	Quality Level 1 - 8 pulses m^2 (\$400/mi^2)
North Block - 13,304 mi^2	\$2,660,800	\$5,321,600
South Block - 6,935 mi^2	\$1,387,000	\$2,774,000
NW Red River Basin total - 20,239 mi^2	\$4,047,800	\$8,095,600

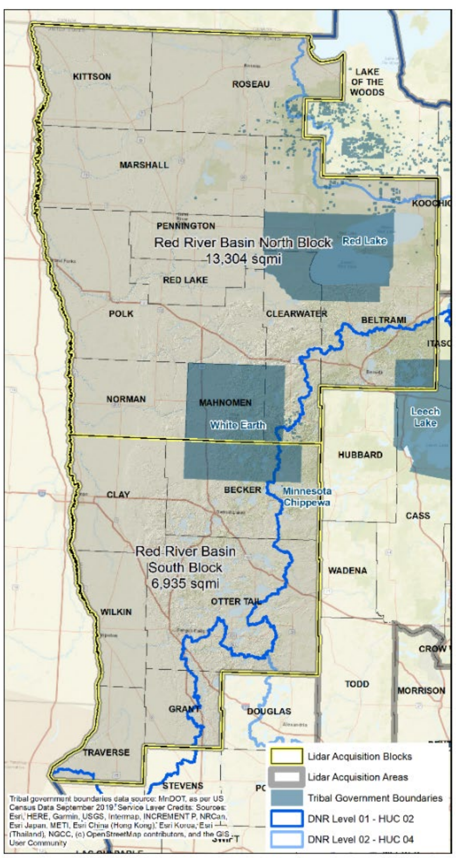


Figure 8: Map of the Red River Basin Lidar Acquisition Area (LAA), with the Red River North and Red River South Lidar Acquisition Blocks (LAB).

Southwest Agriculture Lidar Acquisition Area

The Southwest Agriculture Lidar Acquisition Area (LAA) targets the 28 counties in the southwest part of the state covering over 19,000 square miles. This LAA primarily represents land within the Minnesota River Valley as well as a portion of the Coteau des Prairies formation. The LAA is divided into 3 Lidar Acquisition Blocks (LAB) to maintain a manageable collection size. Estimated acquisition costs are as follows:

LAA/LAB	Quality Level 2 - 2 pulses m^2 (\$200/mi^2)	Quality Level 1 - 8 pulses m^2 (\$400/mi^2)
MN River West Block - 9,789 mi^2	\$1,957,800	\$3,915,600
MN River East Block - 6,183 mi^2	\$1,236,600	\$2,473,200
Missouri-Big Sioux Block - 3,303 mi^2	\$660,600	\$1,321,200
SW Agriculture total - 19,275 mi^2	\$3,855,000	\$7,710,000

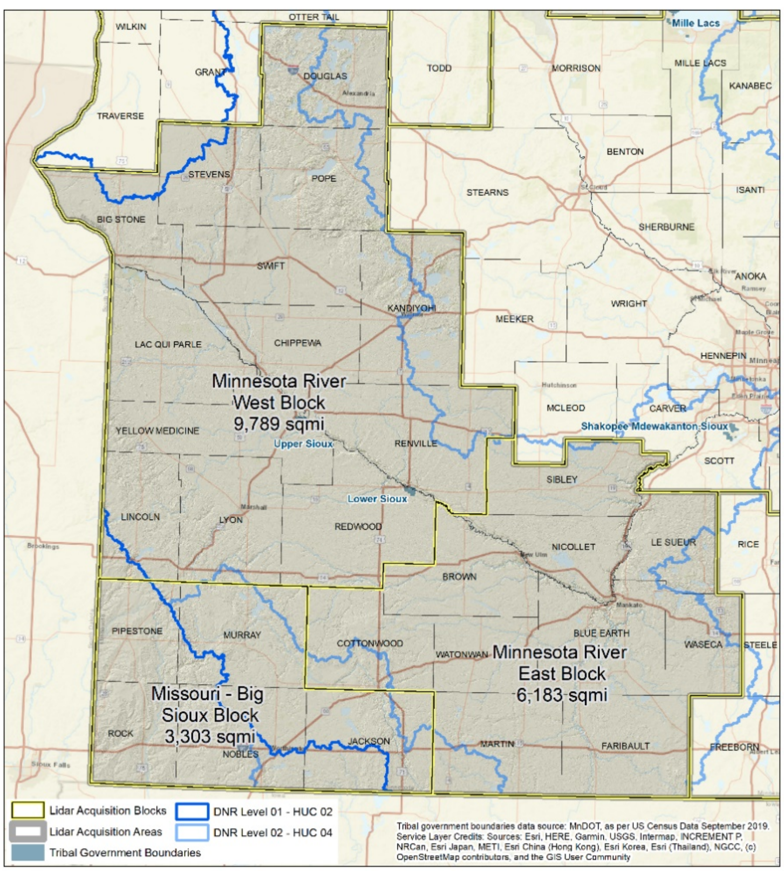


Figure 9: Map of the Southwest Agriculture Lidar Acquisition Area (LAA), with the MN River West, MN River East, and Missouri-Big Sioux Lidar Acquisition Blocks (LAB).

Southeast Driftless Lidar Acquisition Area

The Southeast Driftless Lidar Acquisition Area (LAA) targets the 11 counties in the southeast part of the state covering over 7,000 square miles. This LAA escaped glaciation and is characterized by steep slopes, deep river valleys and karst geology primarily draining directly to the Mississippi River. Estimated acquisition costs are as follows:

LAA/LAB	Quality Level 2 - 2 pulses m^2 (\$200/mi^2)	Quality Level 1 - 8 pulses m^2 (\$400/mi^2)
Lower Mississippi Block - 7,222 mi^2	$1,444,400	$2,888,800
SE Driftless total - 7,222 mi^2	$1,444,400	$2,888,800

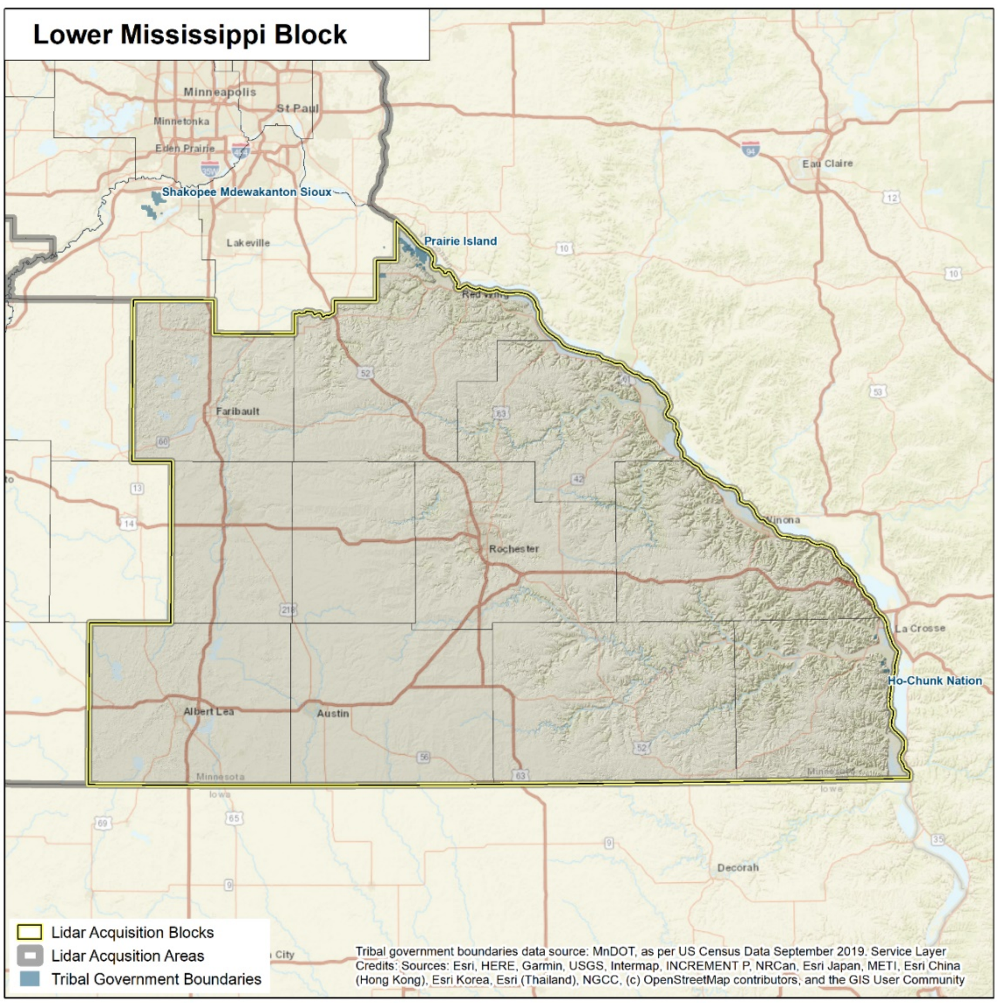


Figure 10: Map of the Southeast Driftless Lidar Acquisition Area (LAA), also known as the Lower Mississippi Lidar Acquisition Block (LAB).

Metro Lidar Acquisition Area

The Metro Lidar Acquisition Area (LAA) targets the 18 counties in and around the metropolitan area covering over 12,000 square miles. This LAA covers land within the central portion of the Mississippi River corridor of Minnesota and is the most populous/developed area. Estimated acquisition costs are as follows:

LAA/LAB	Quality Level 2 - 2 pulses m^2 (\$200/mi^2)	Quality Level 1 - 8 pulses m^2 (\$400/mi^2)
Central Mississippi Block - 12,168 mi^2	\$2,433,600	\$4,867,200
Metro total - 12,168 mi^2	\$2,433,600	\$4,867,200

Figure 11: Map of the Metro Lidar Acquisition Area (LAA), otherwise known as the Central Mississippi Lidar Acquisition Block (LAB).

North Central Lakes Region Lidar Acquisition Area

The North Central Lakes Region Lidar Acquisition Area (LAA) targets 7 counties in the center of lake country covering 11,000 square miles. This LAA covers land within the upper most portion of the Mississippi River corridor of Minnesota composed of many lakes, wetlands, and forested areas. Estimated acquisition costs are as follows:

LAA/LAB	Quality Level 2 - 2 pulses m^2 (\$200/mi^2)	Quality Level 1 - 8 pulses m^2 (\$400/mi^2)
Upper Mississippi Block - 11,071 mi^2	\$2,214,200	\$4,428,400
NC Lakes Region total - 11,071 mi^2	\$2,214,200	\$4,428,400

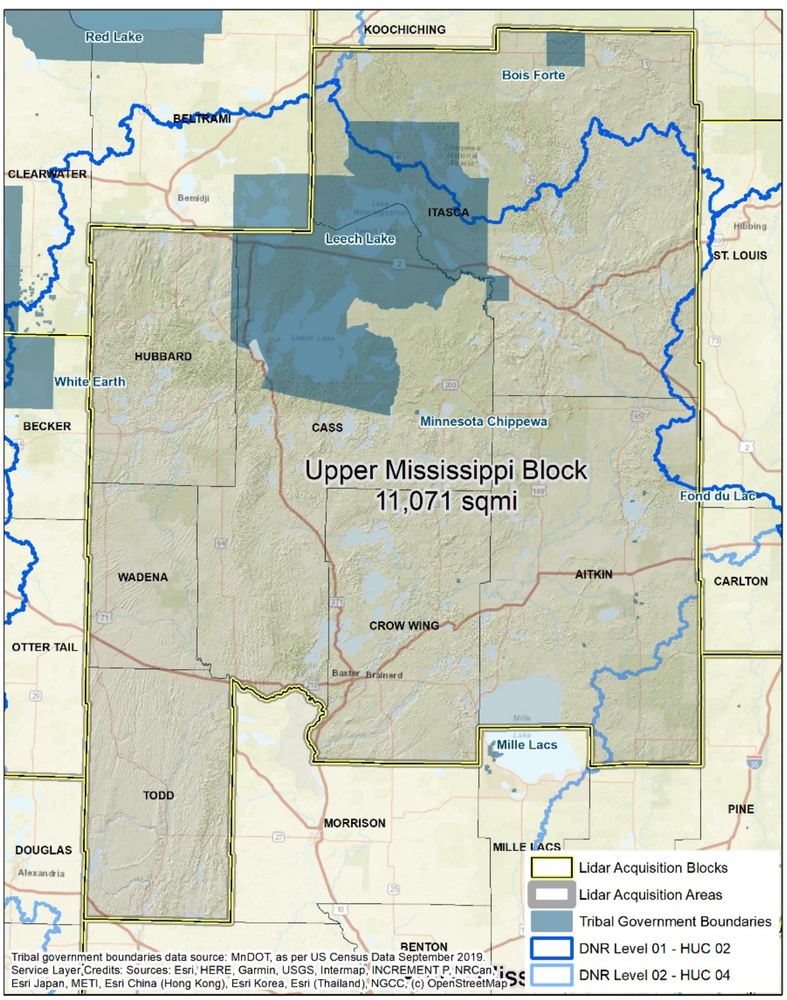


Figure 12: Map of the North Central Lakes Region Lidar Acquisition Area (LAA), otherwise known as the Upper Mississippi Lidar Acquisition Block (LAB).

Northeast Forested Lidar Acquisition Area

The Northeast Forested Lidar Acquisition Area (LAA) targets the 6 counties in Minnesota's NE forested landscape covering over 16,000 square miles. This LAA targets an area composed of heavy tree canopy, lakes, and wetlands and is divided into 2 Lidar Acquisition Blocks (LAB) to maintain a manageable collection size. Due to vested interest in using high density lidar for forest inventory modeling, a portion of Lake County in the Superior National Forest has already been acquired at QL1 in 2018 and those acres have been removed from the LAB area shown in the table below. However, since these data have not yet been submitted to the 3DEP program, 3DGeo is exploring the eligibility of that dataset for submission as in-kind contribution to a BAA. Between that dataset, continued interest in natural resources assessment by the US Forest Service, Counties in the region, the State, and a selection of others, the NE Forested LAA, or at least the Rainy Lake Block, will be submitted as the first area of interest to the upcoming 2019 3DEP BAA for acquisition in spring 2020. The estimated acquisition costs are as follows:

LAA/LAB	Quality Level 2 - 2 pulses m^2 ($200/$mi^2$)	Quality Level 1 - 8 pulses m^2 ($400/$mi^2$)
Rainy Lake Block - 9,291 mi^2	$1,858,200	$3,716,400
Lake Superior Block - 7,245 mi^2	$1,449,000	$2,898,000
NE Forested total - 16,536 m^2	$3,307,200	$6,614,400

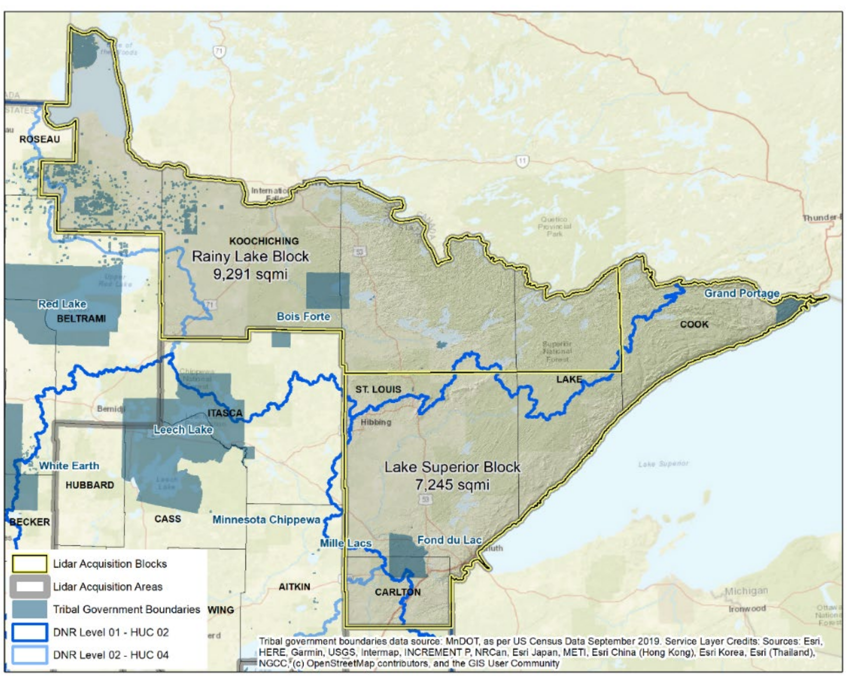


Figure 13: Map of the Northeast Forested Lidar Acquisition Area (LAA), with the Rainy Lake and Lake Superior Lidar Acquisition Blocks (LAB).

Acquisition Specifications

Standards and specifications are essential to facilitate the development and sharing of geospatial data and products. The National Geospatial Program (NGP) standards and specifications define requirements to ensure that all maps and data prepared by NGP, in support of The National Map, are consistent in accuracy, structure, format, style, and content. The USGS 3DEP program sets the minimum Quality Level (QL) at QL2, which has a minimum of two pulses per square meter. Minnesota's previous statewide collection ending 2012 fails to meet this new minimum standard and has less than one pulse per square meter on average.

This Minnesota plan targets a collection at QL1 specifications. At eight pulses per square meter minimum, this level of quality far exceeds QL2 and enables DEMs at 0.5-meter resolution and up to 0.5-foot contour line creation. The higher point density in a QL1 lidar point cloud also enables vast improvements in automated mapping methods for above ground features, like building footprints and vegetation structure. It resolves with greater detail water conveyance features that are often missed because they are too small or hidden underneath vegetation (e.g., obstruction from dense cattail beds and overhanging woody vegetation in small streams). These water conveyance features include sewers, culverts, and other human made infrastructure to move water away from an area. If these features are not identified and utilized in the treatment and correction of digital elevation hydrological modeling, baseline mapping of water flow and direction for water mitigation efforts are left incorrect and inadequate. High density lidar data can vastly improve and speed up the process of mapping these features, both because of the enhanced detail available in high density lidar and because of the improvement in modern algorithms and computational power.

The Minnesota Department of Transportation (MnDOT), for example, collects an average about 700 corridor miles of aerial survey photos data each year. MnDOT calculated savings based on a QL1 collection and found production time savings of up to 60% and digital terrain model (DTM) compilation savings up to 75%. As mentioned in an earlier section of the Plan, there can be significant cost saving in conducting forest inventory using a model assisted approach, where results have shown that the use of high density lidar data for modeling key forest inventory metrics can cut inventory costs by about 55% and add significant value to many tangential projects that are difficult to quantify. Though the resolution and data needs may vary by project and not all projects will see these significant savings, the overall savings are quite apparent and have already paid dividends.

It is critical that the results of this Plan meet and exceed these high-quality data standards to ensure the broadest base of end-user applications and virtually guarantee a higher return on investment. The Minnesota Lidar Plan will follow the most current USGS Base Specifications and will meet or exceed the minimum requirements for USGS 3DEP. The details of most of these specifications are outlined in Appendix B or can be found on the USGS website: USGS Lidar Base Specification.

Project Deliverables

There are many deliverables that are part of a lidar project from start to finish, all of which begin with, and are dependent on, the collection of accurate and high-density source lidar data. To accomplish that, this Plan adopts the collection criteria defined in the USGS lidar Base Specification 2.1, 2019 (LBS) or the most recent specification and will exceed the minimum requirements for deliverables to 3DEP by likely including a few additional deliverables. Unlike early lidar acquisition projects, which focused mostly on the products derived from lidar such as the bare-earth DEM and contour lines, this new Minnesota Lidar Plan places emphasis on the source lidar density and supporting metadata to ensure that the point cloud is of the highest quality, consistency and robustness across all specifications and applications as possible. Details of these lidar deliverables are outlined in Appendix B and can be obtained in further detail from the USGS websites, USGS Lidar Base Specification and 3D Elevation Program (3DEP).

Cost Estimates and Funding Planning

The evolution of lidar technologies that support high density and high accuracy capture of the Earth's surface in 3D has driven higher expectations from product end users and an expansion of lidar derived applications. To meet these expectations, lidar collection missions require specific criteria and flight specifications to meet the lidar base specification (LBS) specifications and achieve expected point density. This can include: lower flight altitudes, multiple passes over the same area, large amounts of swath overlap (> 50%), and cutting-edge technology platforms capable of achieving high point densities from a single aerial swath. Many of these parameters can increase project costs due to the increases in flight time (i.e., increases in fuel and staff time), longer data processing and management time, and infrastructure investments in equipment and/or computing resources.

Although some costs may increase with higher quality higher density data, economies of scale still apply and projects of larger size will not only see costs per square mile decrease considerably, the larger size will entice more investors across the board in the acquisition. In addition, high density lidar point clouds serve a greater amount of business needs and support a wider array of derived products for end user applications, allowing Minnesota to see a greater return on investment (ROI) over a longer period

Vendor Based Cost Estimates for Minnesota

Minnesota's first Lidar collect was an amalgamation of procurement projects from several entities with an estimated range from $100 to $150 per square mile for a total estimated cost of 13.9 million. These acquisitions occurred so long ago, and during a time when available lidar technologies were immature, the costs are not comparable to today's standards (reflected by an asterisk (*) next to these estimates throughout the Plan).

To obtain information about the average cost of lidar at the varying quality levels and project area size ranges, the 3DGeo Committee held informational meetings in person and over the web with nine key lidar vendors on Tuesday, July 31st and Friday, August 2nd at the Minnesota Department of Natural Resources Central Office in St Paul. Each vendor was given a document with topics and questions a couple of weeks ahead of time and 1 hour of discussion with the 3DGeo team. Most of these vendors also provided ample reference materials and have had follow up conversations regarding key topics such as data storage and management and platforms for data distribution.

Below is a table that summarizes the results of the solicitation of cost estimates from these nine vendors.

Quality Level (QL)	Ranges of Project Area per Square Mile	Low End of Cost per Square Mile	High End of Cost per Square Mile	Average Cost per Square Mile
QL-0	500 - 1,000	$400	$550	$475
	1,000 - 5,000	$400	$500	$450
	>5,000	$350	$450	$400
QL-1	500 - 3,000	$300	$450	$375
	3,000 - 5,000	$305	$335	$320
	5,000 - 10,000	$290	$450	$370
	>10,000	$185	$400	$293
QL-2	500 - 3,000	$200	$250	$225
	3,000 - 5,000	$205	$220	$213
	5,000 - 10,000	$150	$205	$178
	>10,000	$175	$190	$183
QL-3*	Not Applicable	$125	$225	$175

Given the obtained estimates and using the average cost per square mile, the following table summarizes the estimated total costs per QL for the entire state. In the Lidar Acquisition Areas of Interest section found earlier in the Plan, these same assumptions were used to obtain the cost estimates for each of the proposed Lidar Acquisition Blocks (LAB). Different regions of the state may result in different cost estimates at the time of data acquisition. For example, the Rainy Lake Block will cost $400 per square mile, above the average cost shown below of $340 per square mile.

Quality Level (QL)	Average Cost per Square Mile	Estimated Cost for All of Minnesota [millions]
QL-0	$445	$38.20
QL-1	$340	$29.40
QL-2	$200	$17.20
QL-3*	$175	$13.90

In addition, the 3DGeo Committee recently submitted an Independent Government Cost Estimate (IGCE) to the USGS to get a more accurate estimation of selected Lidar Acquisition Areas and Blocks. An IGCE provides an estimate of project costs sufficient for project planning and partnership development, but a full and final estimate is completed after award of 3DEP and during the beginning phases of contract development.

Data Management and Distribution

The acquisition of new lidar point cloud data and the creation of lidar-derived data products for Minnesota will require a robust data management and distribution plan. The work to define requirements and create such a plan has not been started; however, as the work proceeds, that information will be shared and updated in this section of the plan.

It is anticipated that the information contained in the Minnesota lidar point cloud data will be used by technicians and scientists to generate landscapes such as ground, buildings, and trees used for mapping, inventory, and modeling purposes. Additionally, digital elevation models and other 3D data will be available for use by citizens of Minnesota to meet a diverse and growing number of business needs. Sectors of application of lidar products include agriculture and precision farming, forest and timber management; water quality, supply, and water quantity analysis; emergency response; Lake Superior coastal zone management; surveying; archeology; and infrastructure and construction management.

The elevation products created from the initial lidar data collection in Minnesota are currently shared in two ways, 1) through direct FTP links and 2) through an interactive web application, MnTOPO, that allows users to view, print, and download (using boundaries of their interest) lidar point cloud tiles or high-resolution lidar derived products.

The data management and distribution system for the *new* lidar point cloud and derivative products will build upon the wide acceptance and use of MnTOPO by the Minnesota geospatial community. Additionally, the new system will consider and incorporate state-of-the-art technology advances since the development of MnTOPO where appropriate, such as cloud-based storage, cloud-based geoprocessing and analysis, and improved distribution models.

Minnesota has a strong tradition of data documentation and data sharing and the intention will be to implement a data storage and distribution solution so that lidar data and derivatives could be available publicly as soon as possible after acquisition and processing is complete. Metadata and data access instructions would be available on Minnesota's geospatial distribution site, the Minnesota Geospatial Commons.

The value of a lidar data and derivative products are determined significantly by the terms under which they can be used, and the confidence of the consumer in the terms of use. When allowed uses are limited or the consumer is not sure of their allowed uses, their risk in using the data is higher and the value is lower. To maximize value and ensure that the terms use for lidar data and derivates are clear the intention is to publish and share them under a simple, explicit, open license. By putting this data into the public domain, it guarantees the data consumer the right and confidence to use the data for any purpose including research, commercial analyses, commercial products, etc. To accomplish this, the plan intends to release data under the Creative Commons Zero license. This license provides a way for data creators to opt out of any rights automatically granted to them in order to effectively put the data into the public domain. It is a "no rights reserved" license. It is simple, common, explicit, and data consumers will clearly understand the terms of use.

While the cost for a new data management and distribution has not been determined, it is anticipated to be higher than the current cost of MnTOPO and FTP support due to the increased size of the data, and the goal of more lidar-derived products. This plan will provide additional details about data management and distribution costs as they are defined along with a potential model for supporting the ongoing costs.

Outreach Plan and Funding Planning

The Minnesota Lidar Plan is a tool to guide lidar acquisition, derivative product development and data distribution over several years. One of the keys to success of the plan's implementation will be to engage and collaborate with the Minnesota community. The USGS has designed this 3DEP SeaSketch platform to assist in such collaborative engagement and communication needs, including having a clearinghouse for gathering spatial interests, project descriptions, and contact information, as well as a forum for posting questions and other communications with interested parties on a group message board. The USGS 3D Elevation Program highly values an engaged and enthused community entering a new lidar acquisition project, as proven by their historical reaction to USGS 3DEP BAAs in the region. The GAC 3DGeo committee provides the framework for communication. Communication about the lidar plan can be divided into two main areas each of which is described below.

General Communications Plan

The GAC 3DGeo Committee will use face to face and webinar lidar stakeholder meetings, email, StoryMaps, and websites to communicate about the lidar project. Topics for emails could include notification of lidar plan document updates, general information about grant submissions, lidar training opportunities and lidar data distribution and product information. Depending on the desired audience for the message, one of two email lists will be used.

1. MnGeo's GIS Newsletter mailing list – this email list reaches over 1,500 GIS professionals in Minnesota. This email list would be used to share information about lidar that would be of interest to a wide audience. Anyone can sign up for this email list. [https://www.mngeo.state.mn.us/newsletter.html]
2. 3DGeo mailing lists – The GAC 3DGeo Committee maintains email lists for members of all its workgroups, including the Data Acquisition Workgroup, which works most directly with lidar collection. This email list would be used to share information that would be considered very technical or specific to a workgroup need.

General information about the lidar effort will also be communicated on the Data Acquisition Workgroup's web page (under the GAC 3DGeo web page. Additionally, information about lidar may be communicated on the through the Minnesota lidar story map.

Communications about Acquisitions, Funding Needs and Opportunities

Collaboration on funding is critical for lidar collection in Minnesota. The acquisition of lidar will be done by region. In order to coordinate partners in the regions defined in the Lidar Acquisition Areas of Interest section of this document, the following steps will be followed.

1. Identify potential partner organizations
2. Hold in-person meetings with partners in location within or near the area of interest and facilitate information sharing, consensus on funding, lidar quality levels, deliverables and other topics to support submission of USGS grant requests and the planning of lidar acquisition with a lidar vendor.
3. Follow up with frequent communication by phone and email and through web-based meetings

This communication and funding section of the plan will be expanded as the lidar plan itself evolves, and there is more experience about the communication approach that works best with Minnesota partners.

After lidar data and derivative products have been acquired, the need for communication how to access those products will be shared using email mailing list described above, as well as on the Minnesota Geospatial Commons. Communication about how to use data will be addressed in conjunction with the 3DGeo Education Workgroup and is covered at a high level in the following section about training needs and support.

Training Needs and Support

The continuing need for lidar education, training, and support is well-demonstrated by states that have acquired it, both in failed efforts to properly fund such efforts, and in success-stories where end users are given ample resources to effectively use such data. Minnesota's Initial lidar collect (2009-2012) included such means to progress and extend the role of educational resources per surrounding state's experiences. As a greater GIS community, we sought to improve lidar-related learning opportunities, and nearly ten years of efficiencies, cost savings, and increased output have been the positive result of such educational activities.

From 2011 – 2012, the Legislative-Citizen Commission for Minnesota Resources (LCCMR) funded a set of 26 workshops, comprised of 6 different lidar educational modules throughout the state. More than 400 GIS professionals across local, state, and federal roles, both public and private, received Minnesota-specific lidar instruction. Those training attendees took cutting-edge techniques and data-driven skills back to their respective shops, to lead efforts in their own corners of Minnesota.

Though previous workshops have given some users a basic knowledge of the dataset, the most recent statewide efforts are approaching a decade in age, training on a dataset that will be much different than the current acquisition. While various entities have offered individual training opportunities since then, those efforts are few and random; not the coordinated, statewide, and thorough educational versions that Minnesota benefitted from in our original lidar collect.

We propose again that lidar education be inextricably tied to *any* state lidar data acquisitions, both for the user of such data, and ultimately to the benefit of the many crucial programs that lidar in Minnesota serves. This can be done by using the existing body of training and teaching material curated over the past decade as a base, then tapping into more recent research, and building from there new applications that high density lidar can serve. End-users need to have a strong functional knowledge of how to apply lidar to a host of disciplines, plus key managerial employees also need to understand high-level applications, benefits, and opportunities gained through lidar usage. Agency heads and leaders throughout the private and public sectors need the knowledge to leverage prospects and the options that lidar gives their staff. Lidar is no longer a singular product or entity, but rather a collection of different data types and their derived datasets that each may serve several very different needs. For Minnesota to maintain a competitive advantage in several lidar-influenced fields, our state's leaders require this understanding.

Additional Resources

To find out more about the topics covered in this plan, learn about lidar efforts nationally and in other states, please see the resources below.

Minnesota Resources

- Minnesota Lidar Plan story map
- Minnesota Lidar Hub site
- Minnesota Geospatial Advisory Council (GAC)'s 3DGeo Committee
- MnGeo's GIS Newsletter

Resources from Other States

Story Maps

- California - California Lidar: A Critical Investment (https://arcg.is/Gnz80)
- Florida - Florida Statewide Lidar (https://arcg.is/1zvjbq)
- Indiana - Indiana Statewide Lidar Planning & Status (https://arcg.is/1GOj1z)
- Washington - Washington State Lidar Plan Story Map (https://wadnr.maps.arcgis.com/apps/Cascade/index.html?appid=b93c17aa1ef24669b656dbaea009b5ce)

USGS National Map (USGS NM)

- Viewer (https://viewer.nationalmap.gov/advanced-viewer/)
- Service Endpoints (https://viewer.nationalmap.gov/services/)
- Data Downloads (https://viewer.nationalmap.gov/basic/)
- 3DEP Viewer (https://apps.nationalmap.gov/3depdem/)

NOAA US Federal Mapping Coordination Map

- Interactive Map - Provides outlines for federal areas of interest for lidar data collection

Glossary

This glossary contains some terms and acronyms used in this document and will be updated when necessary. Additionally, a more complete glossary related to lidar specifications can be found on the USGS website in the latest USGS Lidar Base Specification: Glossary.

Term	Definition
3DGeo	The 3D Geomatics Committee of the Minnesota Geospatial Advisory Council. 3DGeo works to identify and promote the need for planning, funding, acquisition, and management of three-dimensional geomatic data and derived products. The committee engages multiple disciplines in Minnesota for the benefit of its resources and citizens, promoting the value, importance, and use of this complex and voluminous three-dimensional information. See: 3D Geomatics Committee (https://www.mngeo.state.mn.us/committee/3dgeo/)
3DEP	The USGS 3D Elevation Program (https://www.usgs.gov/core-science-systems/ngp/3dep/what-is-3dep)
Bare Earth	Digital elevation data of the terrain free from vegetation, buildings, and other man-made structures. Elevations of the ground.
Breakline	A linear feature that describes a change in the smoothness or continuity of a surface. The two most common forms of breaklines are Soft Breakline and Hard Breakline.
Check Point	A surveyed point (*x, y* or *x, y, z*) used to estimate the positional accuracy of a geospatial dataset against an independent source of greater accuracy. Check points are independent from, and may never be used as, control points on the same project.
Commons	Minnesota Geospatial Commons is a collaborative space for users and publishers of Minnesota's geospatial resources. See: Minnesota Geospatial Commons (https://gisdata.mn.gov/)
Confidence Level	The percentage of points within a dataset that are estimated to meet the stated accuracy; for example, accuracy reported at the 95-percent confidence level means that 95 percent of the positions in the dataset will have an error with respect to true ground position that are equal to or smaller than the reported accuracy value.
Contour	A contour or contour line joins points of equal elevation.

Term	Definition
Control Point	A surveyed point used to geometrically adjust a lidar dataset to establish its positional accuracy relative to the real world. Control points are independent from, and may never be used as, check points on the same project.
Datum	A set of reference points on the Earth's surface against which position measurements are made, and (usually) an associated model of the shape of the Earth (reference ellipsoid) to define a geographic coordinate system. Horizontal datums (for example, the North American Datum of 1983 [NAD 83]) are used for describing a point on the Earth's surface, in latitude and longitude or another coordinate system. Vertical datums (for example, the North American Vertical Datum of 1988 [NAVD 88]) are used to measure elevations or depths. In engineering and drafting, a datum is a reference point, surface, or axis on an object against which measurements are made.
Digital Elevation Model Resolution	The linear size of each cell of a raster DEM. Features smaller than the cell size cannot be explicitly represented in a raster model. DEM resolution may also be referred to as cell size, grid spacing, or ground sample distance.
Digital Surface Model	Like DEMs, except they may depict the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare-earth. DSMs are especially relevant for telecommunications management, air safety, forest management, and 3D modeling and simulation.
Digital Terrain Model	As used in the United States, a "DTM" is a vector dataset composed of 3D breaklines and regularly spaced 3D mass points, typically created through stereo photogrammetry, that characterize the shape of the bare-earth terrain. Breaklines more precisely delineate linear features whose shape and location would otherwise be lost. A DTM is not a surface model and its component elements are discrete and not continuous; a TIN or DEM surface must be derived from the DTM. Surfaces derived from DTMs can represent distinctive terrain features much better than those generated solely from gridded elevation measurements. A lidar point dataset combined with ancillary breaklines is also considered a DTM.
GAC	Minnesota Geospatial Council. The GAC is a twenty-three-member council that acts as a coordinating body for the Minnesota geospatial community. It represents a cross-section of organizations that include counties, cities, universities, business, nonprofit organizations, federal and state agencies, tribal government, and other stakeholder groups that benefit from geospatial technology. See: [Minnesota Geospatial Advisory Council (https://www.mngeo.state.mn.us/councils/statewide/index.html)](https://www.mngeo.state.mn.us/councils/statewide/index.html)

Term	Definition
Geomatics	The discipline of gathering, storing, processing, and delivering spatially referenced geographic information
Hydrologically Conditioned	Processing of a DEM or TIN so that the flow of water is continuous across the entire terrain surface, including the removal of all isolated sinks or pits. The only sinks that are retained are the real ones on the landscape. Although hydrologically enforced is relevant to drainage features that generally are mapped, hydrologically conditioned is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether that flow is in a stream channel or not. The purpose for continuous flow is so that relations and (or) links among basins and (or) catchments can be known for large areas.
Hydrologically Flattened	Processing of a lidar-derived surface (DEM or TIN) so that mapped waterbodies, streams, rivers, reservoirs, and other cartographically polygonal water surfaces are flat and, where appropriate, level from bank to bank. Additionally, surfaces of streams, rivers, and long reservoirs demonstrate a gradient change in elevation along their length, which is consistent with their natural behavior and the surrounding topography. In traditional maps that are compiled photogrammetrically, this process is accomplished automatically through the inclusion of measured breaklines in the DTM; however, because lidar does not inherently include breaklines, a DEM or TIN derived solely from lidar points will depict water surfaces with unsightly and unnatural artifacts of triangulation. The process of hydro-flattening typically involves the addition of breaklines along the banks of specified waterbodies, streams, rivers, and ponds. These breaklines establish elevations for the water surfaces that are consistent with the surrounding topography and produce aesthetically acceptable water surfaces in the final DEM or TIN. Unlike hydro-conditioning and hydro-enforcement, hydro-flattening is not driven by any hydrologic and hydraulic (H&H) modeling requirements but solely by cartographic mapping needs.
Hydrologically Enforced	Processing of mapped waterbodies so that lakes and reservoirs are level and so that streams and rivers flow downhill; for example, a DEM, TIN, or topographic contour dataset with elevations removed from the tops of selected drainage structures (bridges and culverts) to depict the terrain under those structures. Hydro-enforcement enables hydrologic and hydraulic models to depict water flowing under these structures, rather than appearing in the computer model to be dammed by them because of road deck elevations higher than the water levels. Hydro-enforced TINs also use breaklines along shorelines and stream centerlines (for example, where these breaklines form the edges of TIN triangles along the alignment of drainage features). Shore breaklines for streams and rivers would be 3D breaklines with elevations that decrease as the stream flows downstream; however, shore breaklines for lakes or reservoirs would have the same elevation for the entire shoreline if the water surface is known or assumed to be level throughout.

Term	Definition
LAS	A public file format for the interchange of 3D point cloud data between data users. The file extension is ".las"
MnGeo	Minnesota's Geospatial Information Office (https://www.mngeo.state.mn.us/)
MnTOPO	MnTOPO is a web application for viewing, printing and downloading high-resolution elevation data for the State of Minnesota created from the initial lidar data collection. See: MnTOPO web application (https://www.dnr.state.mn.us/maps/mntopo/index.html)
Nonvegetated Vertical Accuracy	Replaces fundamental vertical accuracy (FVA). The vertical accuracy at the 95-percent confidence level in nonvegetated open terrain, where errors should approximate a normal distribution.
Vegetated Vertical Accuracy	Replaces supplemental vertical accuracy (SVA) and CVA. An estimate of the vertical accuracy, based on the 95th percentile, in vegetated terrain where errors do not necessarily approximate a normal distribution.

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Open Geospatial Consortium, Inc. (OGC), 2001, OpenGIS® Implementation Specification: Coordinate Transformation Services (CT)—Revision 1: Open Geospatial Consortium, Inc., 117 p. accessed September 30, 2019, at Coordinate Transformation Service (http://www.opengeospatial.org/standards/ct).

Appendix A: Minnesota Lidar Plan Authors

Team Member	Organization
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Appendix B: Lidar Deliverables Specifications and Details

Spatial Data Standards

Defined Coordinate Reference System

Lidar data and all related or derived data and products shall be processed and delivered in a single Coordinate Reference System (CRS).

- Each project shall be processed and delivered in a single CRS, except in cases where a project area covers multiple CRSs such that processing in a single CRS would introduce unacceptable distortions in part of the project area (e.g., between UTM zones in Minnesota). In such cases, the project area is to be split into subareas appropriate for each CRS. Each subarea shall be processed and delivered as a separate subproject with its own CRS.
- Standards for a single project will apply to each subproject, notably the inclusion of the required buffer area and delivery of DPA and BPA boundaries. The DPA boundaries of adjacent subareas shall have topologically coincident boundaries along their common borders. The individual DPA boundaries are necessary to ensure that the adjacent subarea datasets can subsequently be merged in a single CRS without introducing duplicate points. For each project or subarea, all spatial data within the area shall be in the same CRS.

Datums

Geospatial data must be tied to a clearly and precisely defined reference, or datum.

- The horizontal datum for latitude and longitude and ellipsoid heights will be the North American Datum of 1983 (NAD 83) using the most recent NGS-published adjustment (currently NAD 83, epoch 2010.00, realization of 2011).
- The vertical datum for orthometric heights will be the North American Vertical Datum of 1988 (NAVD 88).
- The geoid model used to convert between ellipsoid heights and orthometric heights will be the latest hybrid geoid model of NGS, supporting the latest realization of NAD 83 (currently [2017] Geoid12b model).

Time of Global Positioning System Data

The time of GPS data shall be recorded as Adjusted GPS Time at a precision sufficient to allow unique timestamps for each pulse.

- Adjusted GPS Time is defined to be standard (or satellite) GPS time minus 109. The encoding tag in the LAS header shall be properly set.

Tiles

3DEP developed an authoritative, 1-kilometer (km) by 1-km national indexing scheme for the conterminous United States. This single, non-overlapping tile index will facilitate a more consistent, standardized elevation data acquisition process. The national indexing scheme has the following characteristics:

- Coordinate reference system is Albers Equal Area (European Petroleum Survey Group [EPSG] code 6350), with XYZ units in meters.
- Each tile is 1 square kilometer (km2) in area.
- The standard naming convention is based on the easting and northing locations of the lower left corner for each tile, for ease of searching. An example of a tile name for a 1-km tile isw0002n0612
- Tiles can be grouped by various attributes (for example, by county, State, or hydrologic unit code), but each tile is part of one and only one group.
- New project boundaries will be extended to complete the nearest 1-km tile and enlarged as necessary to avoid leaving gaps between existing lidar collections and planned projects

Deliverables Required by USGS 3DEP

Survey Report

The survey report describes information associated with the control points and check points used in the project.

- Control points - used to calibrate and process the lidar and derivative data.
- Check points - used to validate

Collection Report / Mission Report

The mission report details the mission planning and the flight information, which must include:

- Aircraft
    - The aircraft make, model, and tail number.
- Lift
    - Unique ID for each lift.
    - The take-off and landing times for each lift.
- Lidar Instrumentation
    - The instrument manufacturer, model, and serial number.
    - The date of the instrument's most recent factory inspection/calibration.
    - All inflight instrument anomalies and any inflight changes in settings.
    - Weather Conditions
    - General weather conditions.
    - General observed ground conditions.
    - All inflight disturbances and notable head/tail/crosswinds.

Processing Report

- Calibration and instrument settings by lift and identified by the lift ID.
- Classification methods.
- Derived product generation procedures including methodology used for breakline collection and hydro-flattening (see the “Hydro-Flattening” section and appendix 2 for more information on hydro-flattening).
- Methodology used for breakline collection and hydro-flattening

QA/QC report

The QA/QC report details the procedures for analysis, accuracy assessment, and validation of the project data, including the following:

- The expected horizontal accuracy of the lidar data, as described in ASPRS (2014).
- The assessed relative vertical accuracy of the point data (smooth surface repeatability and overlap consistency). Relative vertical accuracy requirements are listed in LBS-table 2.
- The assessed NVA of the unclassified lidar data in accordance with the guidelines set forth in ASPRS (2014).
- Absolute vertical accuracy requirements for the unclassified point data using the ASPRS methodology are listed in table 4.
- The assessed NVA and VVA of the bare-earth surface in accordance with the guidelines set forth in ASPRS (2014).
- Absolute vertical accuracy requirements using the ASPRS methodology for the bare-earth DEM are listed in LBS-table 4.
- QA/QC analysis materials for the absolute vertical accuracy assessment.

Lidar Swath Polygon

A georeferenced, polygonal representation of the detailed extents of each lidar swath collected, as a GIS layer. The goal is a set of polygons that define the area covered by the swaths, not merely the points collected in the swaths.

- Polygon Extents
  - The extents shall be those of the actual coverage of the collected swath, exclusive of peripheral TIN artifacts. Minimum bounding rectangles or simplified rectangles are not acceptable. The boundary will generally follow the overall shape of the swath as defined by the points tagged as Edge of Flightline. Perimeter incursions into the swath, such as those caused by waterbodies, should not be followed.

- Attributes
  - The Project Name (string format).
  - The Start Date and Time of the swath (date format, minute resolution).
  - The End Date and Time of the swath (date format, minute resolution).
  - The lift’s unique ID (string format).
  - The unique File Source ID of the swath (string format).
  - The type of swath: “Project,” “Cross-tie,” “Fill-in,” “Calibration,” or “Other” (string format).

- Format
    - Esri polygon shapefile or geodatabase is required.

Product metadata

FGDC-compliant, EML format metadata shall pass the USGS Metadata Parser (MP) without errors.
One XML file is required for each of the following deliverable product groups:

- Classified point data.
- Bare-earth DEMs.
- Breaklines.
- Any other datasets delivered (digital surface models [DSM], intensity images, height above ground surfaces, and others).

Metadata files for individual data files within a deliverable product group are acceptable but are not required.

Metadata Tags

A block of lidar-related metadata tags specified by the USGS shall be included in the CSDGM (FGDC, 1998) metadata files for all lidar data deliverables. All tags are required.

Classified Point Cloud Data

Classified point data deliverables shall include or conform to the following procedures and specifications:

- Project Swaths
    - Project swaths, returns, and collected points shall be fully calibrated, adjusted to ground, classified, and segmented into the tile scheme.
    - Project swaths exclude calibration swaths, cross-ties, and other swaths not used, and not intended to be used, for product generation.
    - Each swath shall be assigned a unique file source ID, and each point within the swath shall be assigned a point source ID equal to the file source ID.
        - The point source ID on each point shall be persisted unchanged throughout all processing and delivery.
        - The file source ID for tiled LAS files shall be set to 0.
- Point Cloud format must be in LAS Specification version 1.4, PDRF 6, 7, 8, 9, or 10.
    - GPS times recorded as Adjusted GPS Time at a precision sufficient to allow unique timestamps for each pulse.
    - Tiled without overlap, using the project tiling scheme for delivery to USGS.
    - Classification, as defined in table 5, at a minimum.
        - Point classification is to be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, lifts, or other non-natural divisions will be cause for rejection of the entire deliverable.
        - All points not identified as withheld shall be properly classified.
        - No points in the classified LAS deliverable may remain assigned to class 0.

        - Model key points, if calculated, shall be identified using the key point bit flag as defined in LAS specification version 1.4–R13 (ASPRS, 2011). Model key points may, in addition, be identified using class 8 at the discretion of the data producer.
        - No classification code or value may be used to identify overage (overlap) points. All overage (overlap) points shall be identified using the overlap bit flag, as defined in LAS specification version 1.4–R13 (ASPRS, 2011).

- No data voids
    - Data voids in lidar are gaps in the point data coverage caused by surface absorbance, scattering, or refraction of the lidar pulse (that is, where laser pulse energy is not returned to the sensor), instrument or processing anomalies or failure, obstruction of the lidar pulse, or improper collection because of flight plans.
    - A data void is considered to be any area greater than or equal to (4 × ANPS)2, which is measured using first returns only.
    - Data voids within a single swath are not acceptable, except in the following circumstances:
        - where caused by waterbodies;
        - where caused by areas of low near infrared reflectivity, such as asphalt or composition roofing;
        - where caused by lidar shadowing from buildings or other features; or
        - where appropriately filled in by another swath.
- Overage (Overlap) and Withheld flags set as appropriate.
    - Although strictly speaking, the term "overlap" would mean all lidar points lying within any overlapping areas of two or more swaths, the overlap bit flag is intended to identify overage points, which are only a subset of overlap points that are not necessary to form a complete single, nonoverlapped, gap-free coverage with respect to the adjacent swaths .
    - This plan defines additional overlap criteria for Minnesota to support construction of statewide seamless data products. These criteria include:
    - Overage with Adjacent Historical Lidar Data
        - Historical lidar data is any previously collected data.
        - New Lidar and Existing Lidar Overage
            - Overage should be 50% of the swath of the existing lidar
            - New lidar acquisition must include a buffer of 1-kilometer to accommodate future lidar acquisitions.
        - Overlap of two datasets must be statistically sufficient to
            - Support development of seamless data products with smooth transitions.
            - Support projection transformation shifts.
- Intensity values normalized to 16-bit. *See* LAS specification version 1.4–R13 (ASPRS, 2011) for additional information.
- Waveform data, if collected, in external auxiliary files with the extension ".wdp". *See* LAS specification version 1.4–R13 (ASPRS, 2011) for additional information.
- Correct and properly formatted georeference information as WKT (OGC, 2001) included in all LAS file headers.

Bare-Earth Surface Raster (Digital Elevation Model)

- Bare-earth DEM, generated to the limits of the DPA, without overage (see Overage requirements above).
- DEM resolution as shown in the LBS Table 6.
- Format
    - 32-bit floating point raster GeoTIFF raster format.
    - The NODATA value of '-999999' shall be defined in GDAL_NODATA tag #42113.
    - GDAL version 2.4.0, or as otherwise agreed to in advance and specified in the Task Order, shall be used to populate GeoTIFF keys and tags.
    - Additional requirements for GeoTIFF tiling, compression, and internal overviews may be referenced in Task Orders.
- DEM data shall be in the same CRS as the lidar data.
- Georeference information in or accompanying each raster file, as appropriate for the file format. This information shall include both horizontal and vertical systems; the vertical system name shall include the geoid model used to convert from ellipsoid heights to orthometric heights.
- Tiled delivery without overlap to support transfer to USGS for 3DEP.
- DEM tiles with no edge artifacts or mismatch. A quilted appearance in the overall DEM surface will be cause for rejection of the entire DEM deliverable, whether the variations are caused by differences in processing quality or character among tiles, swaths, lifts, or other artificial divisions.
- Void areas (for example, areas outside the BPA but within the project tiling scheme) coded using a unique NODATA value '-999999' and shall be defined in GDAL_NODATA tag #42113.
- Hydro-flattening as outlined in the "Hydro-Flattening" section. Depressions (sinks), whether natural or man-made, are not to be filled (as in hydro-conditioning). The methodology used for hydro-flattening is at the discretion of the data producer (refer to appendix 2 for more information on hydro-flattening).
- Bridges removed from the surface (refer to the "Glossary" section for the definition of "bridge").
- Road or other travel ways over culverts remain intact in the surface (refer to the "Glossary" section for the definition of a culvert).
- A report on the assessed absolute vertical accuracy of the bare-earth surface in accordance with the guidelines set forth in ASPRS (2014). Absolute vertical accuracy requirements using the ASPRS methodology for the bare-earth DEM are listed in table 4.
- QA/QC analysis materials used in the assessment of absolute accuracy.

Enhancements or Additions that Exceed the 3DEP Base Requirements

Each of the following additions and enhancements have details that are further described in other publications, namely the USGS websites, USGS Lidar Base Specification and 3D Elevation Program (3DEP), those offered in the References and Other Resources sections of the Plan, and listed here:

- Additions to the Minimum Lidar Classification Scheme (additional point cloud classifications)
- Additions to the Hydro Flattening Requirements for Inland Lakes and Ponds
- Additions to the Hydro Flattening Requirements for Inland Rivers and Streams
- Hydro Enforced Digital Elevation Model (DEM)
- Digital Surface Model (DSM, non-hydroflattened)
- Machine generated contours
- Machine generated building footprints
- Hillshades
- Normalized Intensity Image
- Other Unknown Stakeholder Desired/Expected Products

Appendix C: Land Cover Composition per Lidar Acquisition Block

Metro Lidar Acquisition Area Central Mississippi River Lidar Acquisition Block (LAB)

Land Cover Class	Area, square miles
Open Water	512
Developed, Open Space	636
Developed, Low Intensity	465
Developed, Medium Intensity	288
Developed, High Intensity	115
Barren Land	20
Deciduous Forest	1974
Evergreen Forest	77
Mixed Forest	158
Shrub/Scrub	33
Herbaceous	77
Hay/Pasture	1577
Cultivated Crops	4031
Woody Wetlands	840
Emergent Herbaceous Wetlands	1210
Total	12013

Table 2: Land Cover Class composition in the Metro Lidar Acquisition Area Central Mississippi River Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

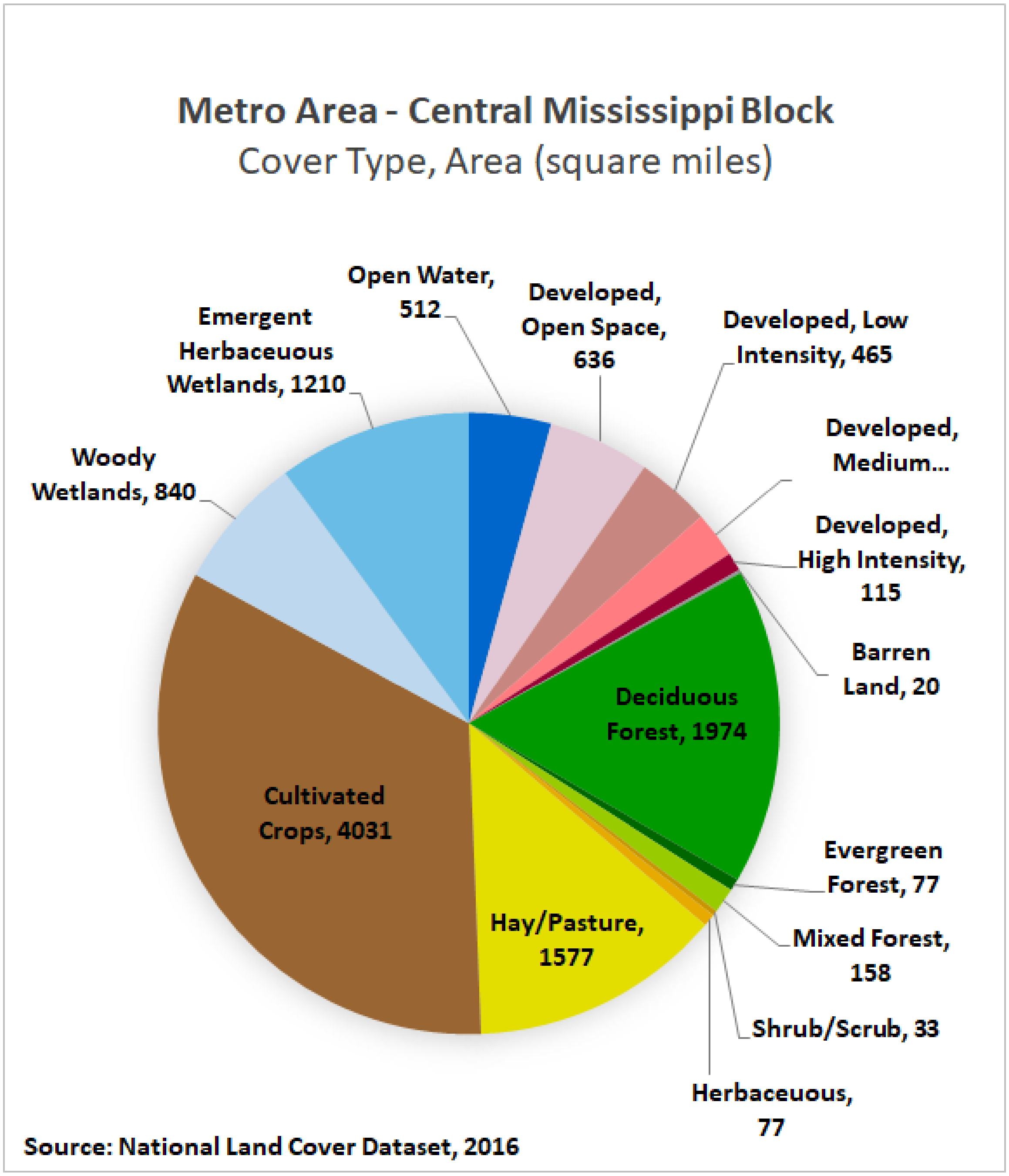

Figure 14: Land Cover Class composition in the Metro Lidar Acquisition Area Central Mississippi River Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

North Central Lidar Acquisition Area Upper Mississippi River Lidar Acquisition Block (LAB)

Land Cover Class	Area, square miles
Open Water	896
Developed, Open Space	278
Developed, Low Intensity	61
Developed, Medium Intensity	18
Developed, High Intensity	5
Barren Land	14
Deciduous Forest	2913
Evergreen Forest	362
Mixed Forest	846
Shrub/Scrub	273
Herbaceous	149
Hay/Pasture	714
Cultivated Crops	650
Woody Wetlands	2770
Emergent Herbaceous Wetlands	1120
Total	11069

Table 3: Land Cover Class composition in the North Central Lidar Acquisition Area Upper Mississippi River Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

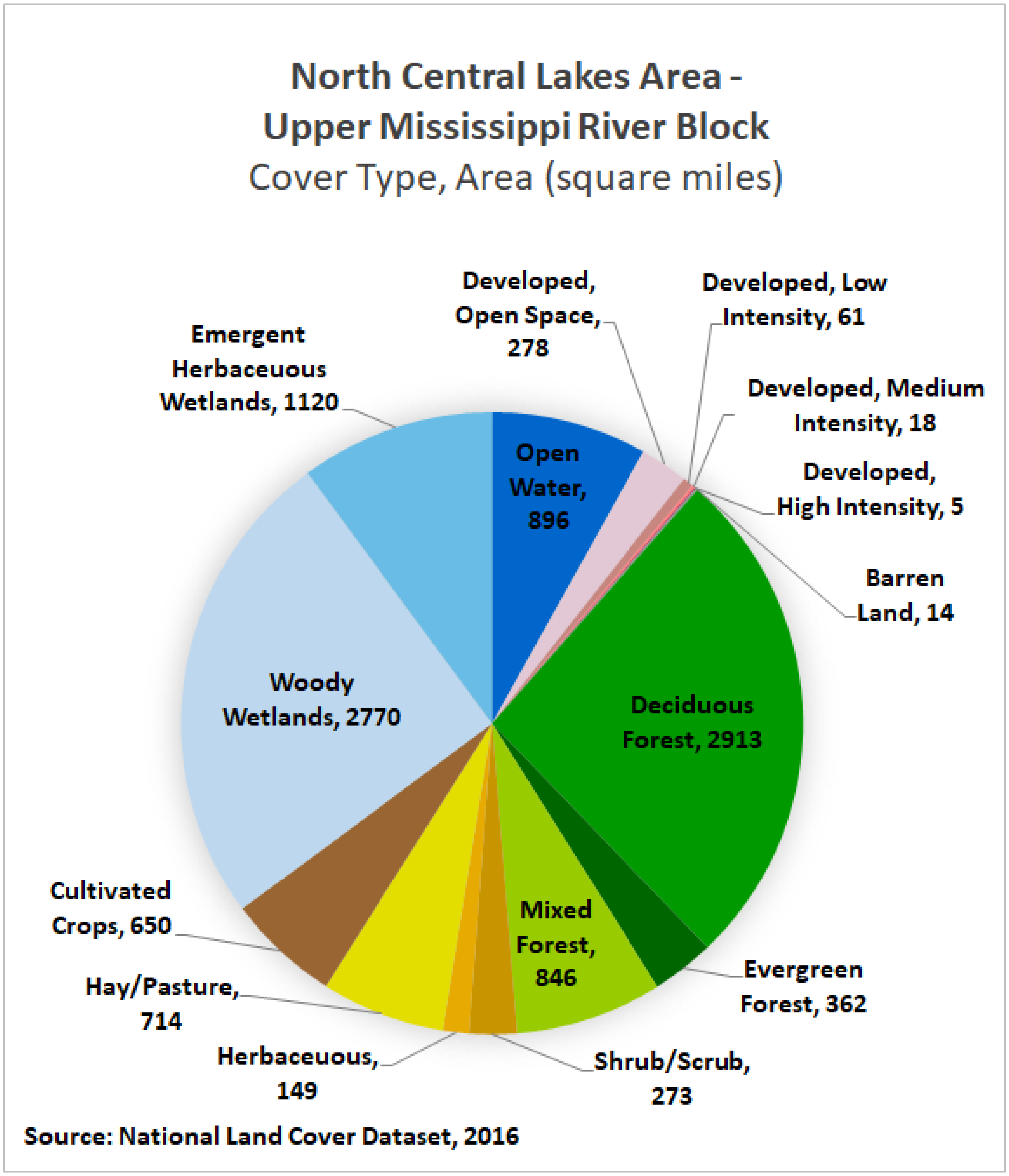

Figure 15: Land Cover Class composition in the North Central Lidar Acquisition Area Upper Mississippi River Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

North East Forested Lidar Acquisition Area Upper Lake Superior Lidar Acquisition Block (LAB)

Land Cover Class	Area, square miles
Open Water	322
Developed, Open Space	145
Developed, Low Intensity	45
Developed, Medium Intensity	24
Developed, High Intensity	9
Barren Land	64
Deciduous Forest	990
Evergreen Forest	677
Mixed Forest	1257
Shrub/Scrub	269
Herbaceous	129
Hay/Pasture	166
Cultivated Crops	8
Woody Wetlands	2634
Emergent Herbaceous Wetlands	192
Total	6931

Table 3: Land Cover Class composition in the North East Forested Lidar Acquisition Area Upper Lake Superior Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

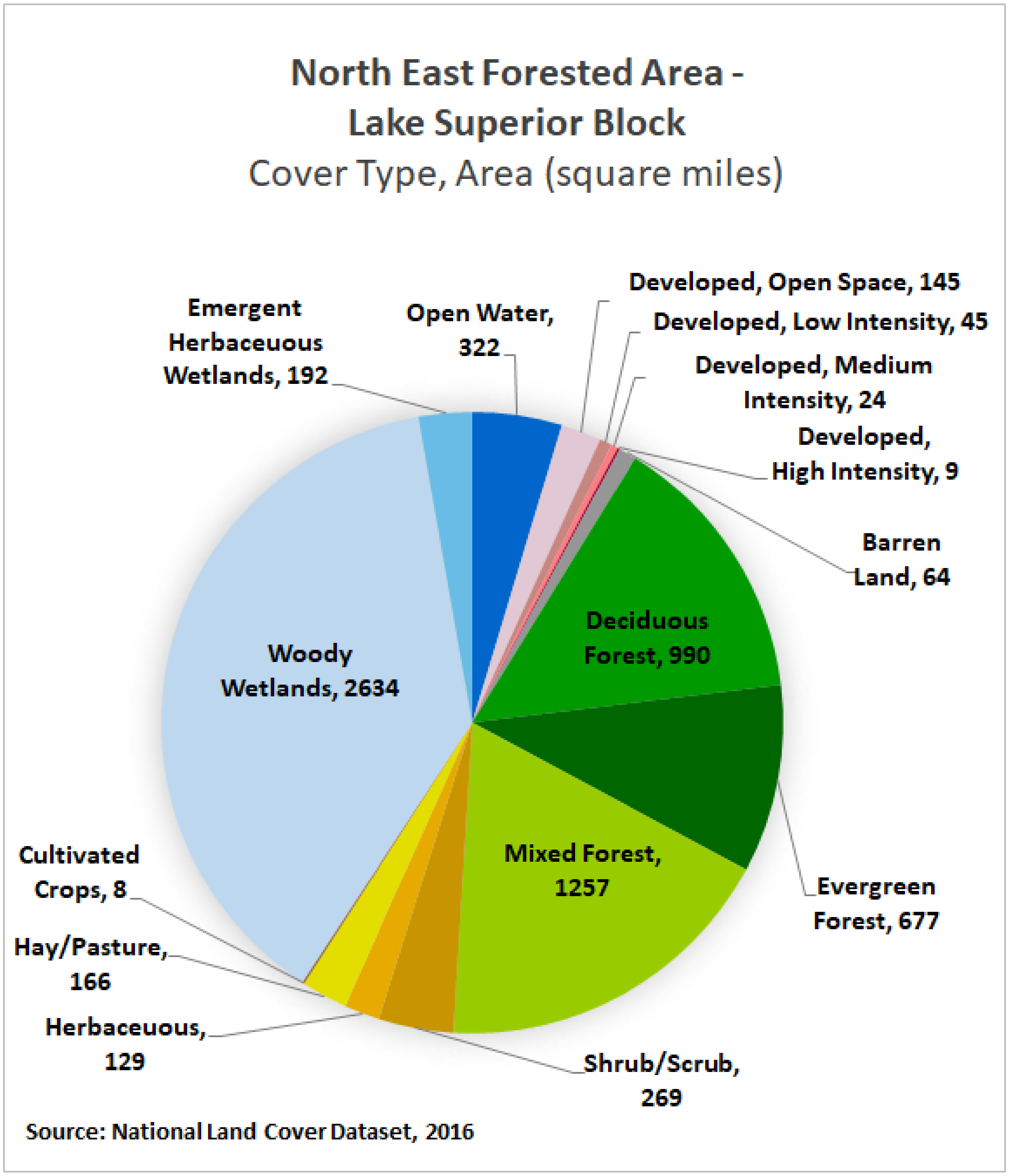

Figure 16: Land Cover Class composition in the North East Lidar Acquisition Area Lake Superior Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

North East Forested Lidar Acquisition Area Upper Rainy Lake Lidar Acquisition Block (LAB)

Table 4: Land Cover Class composition in the North East Forested Lidar Acquisition Area Upper Rainy Lake Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

Land Cover Class	Area, square miles
Open Water	733
Developed, Open Space	86
Developed, Low Intensity	23
Developed, Medium Intensity	9
Developed, High Intensity	2
Barren Land	18
Deciduous Forest	544
Evergreen Forest	498
Mixed Forest	1333
Shrub/Scrub	331
Herbaceous	141
Hay/Pasture	77
Cultivated Crops	101
Woody Wetlands	4296
Emergent Herbaceous Wetlands	786
Total	8978

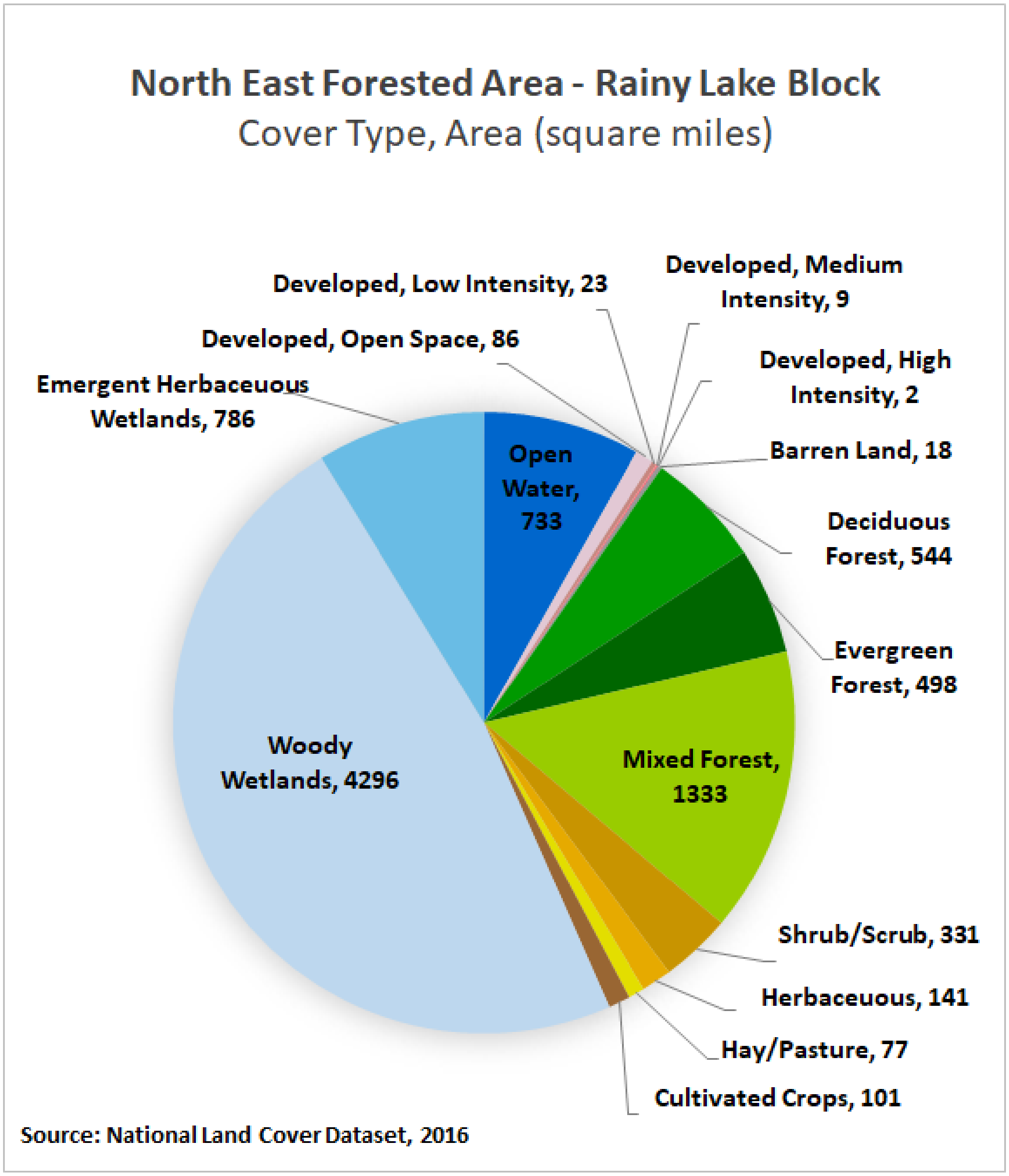

Figure 17: Land Cover Class composition in the North East Forested Lidar Acquisition Area Upper Rainy Lake Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

Red River Lidar Acquisition Area North Lidar Acquisition Block (LAB)

Land Cover Class	Area, square miles
Open Water	338
Developed, Open Space	321
Developed, Low Intensity	71
Developed, Medium Intensity	12
Developed, High Intensity	3
Barren Land	13
Deciduous Forest	1107
Evergreen Forest	120
Mixed Forest	209
Shrub/Scrub	33
Herbaceous	62
Hay/Pasture	459
Cultivated Crops	6052
Woody Wetlands	2123
Emergent Herbaceous Wetlands	2114
Total	13037

Table 5: Land Cover Class composition in the Red River Lidar Acquisition Area North Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

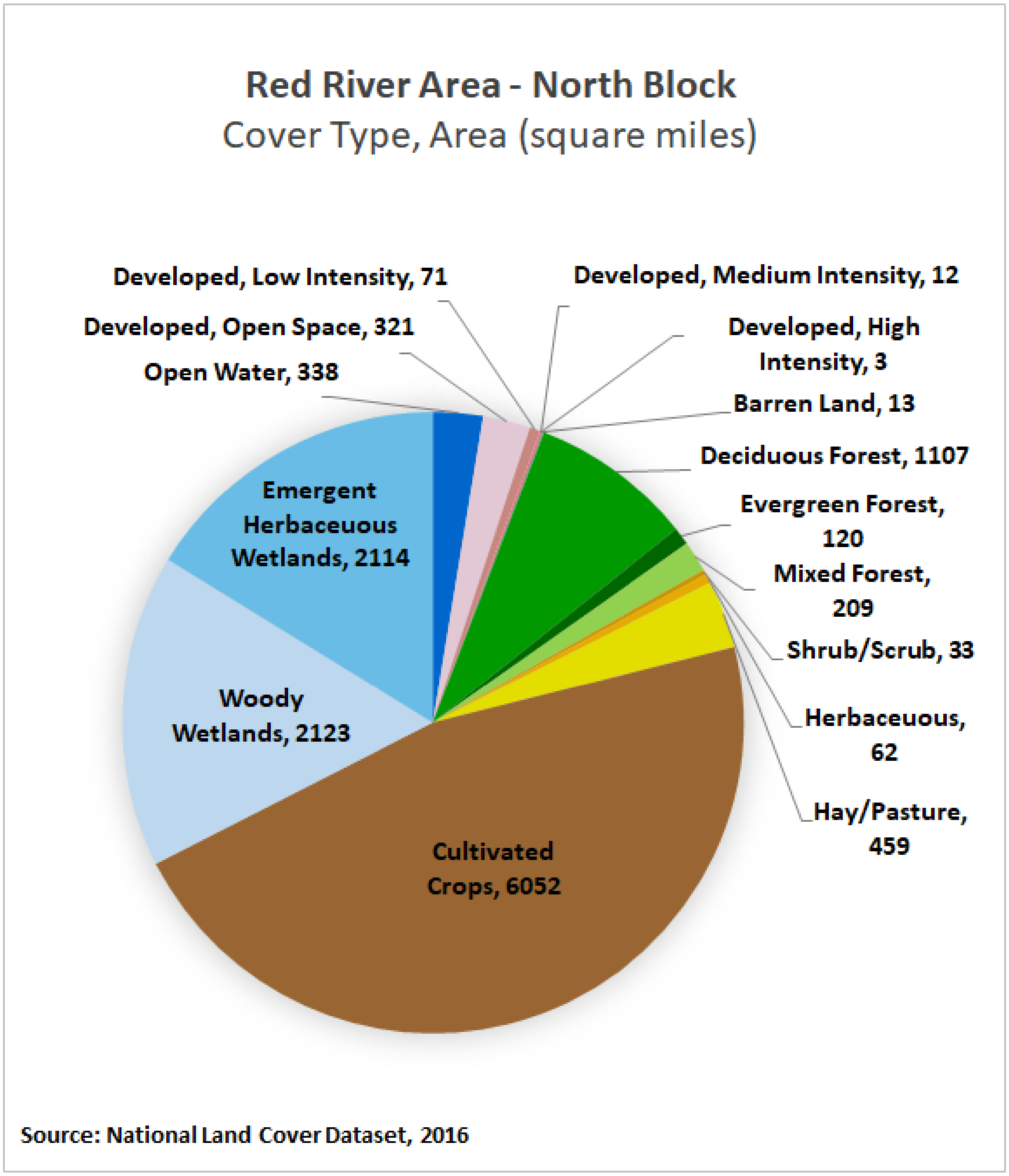

Figure 18: Land Cover Class composition in the Red River Lidar Acquisition Area North Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

Red River Lidar Acquisition Area South Lidar Acquisition Block (LAB)

Land Cover Class	Area, square miles
Open Water	487
Developed, Open Space	227
Developed, Low Intensity	48
Developed, Medium Intensity	14
Developed, High Intensity	4
Barren Land	8
Deciduous Forest	831
Evergreen Forest	61
Mixed Forest	78
Shrub/Scrub	19
Herbaceous	68
Hay/Pasture	460
Cultivated Crops	3753
Woody Wetlands	170
Emergent Herbaceous Wetlands	569
Total	6797

Table 6: Land Cover Class composition in the Red River Lidar Acquisition Area South Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

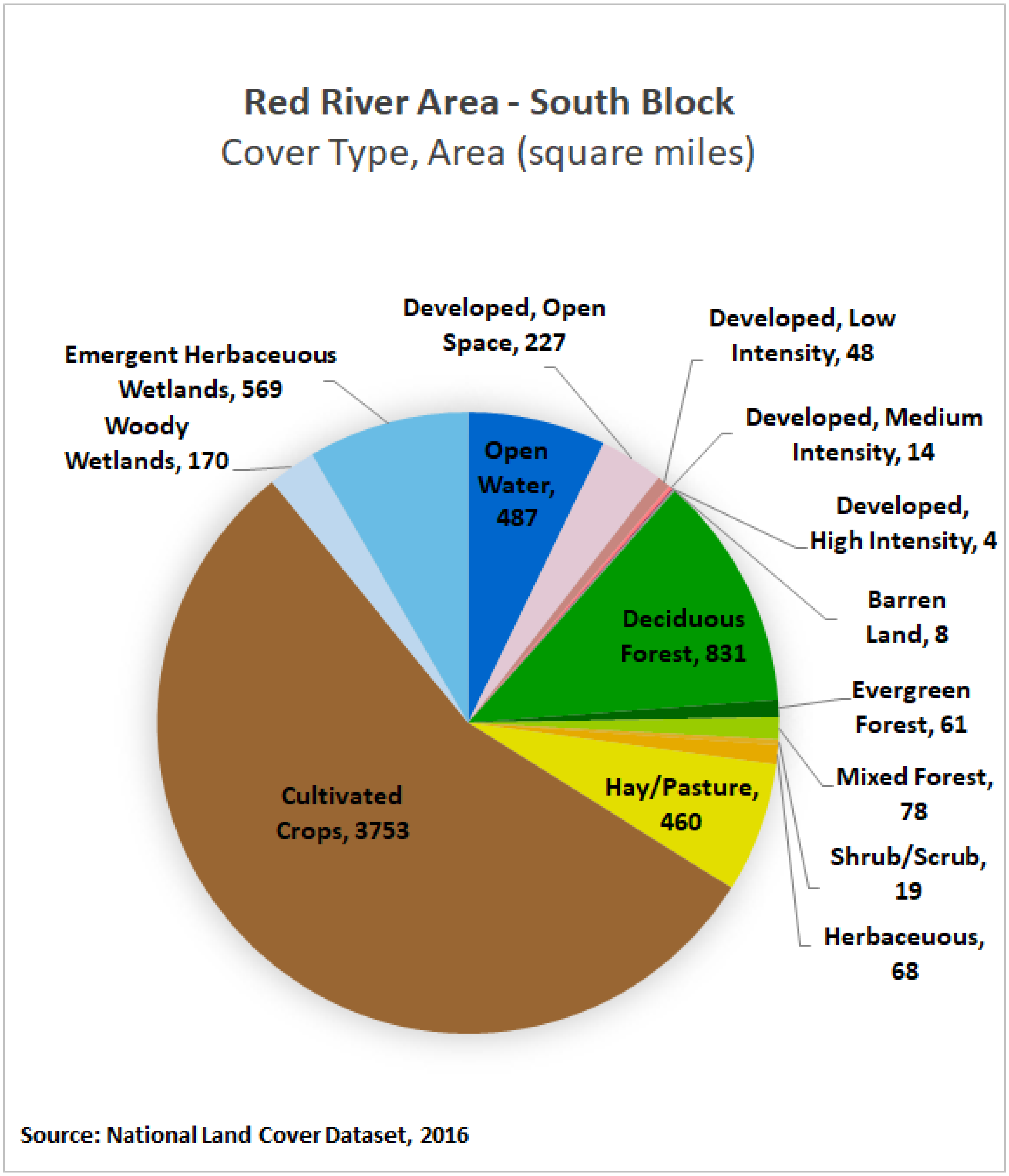

Figure 19: Land Cover Class composition in the Red River Lidar Acquisition Area North Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

South East Lidar Acquisition Area Driftless Lidar Acquisition Block (LAB)

Land Cover Class	Area, square miles
Open Water	127
Developed, Open Space	247
Developed, Low Intensity	140
Developed, Medium Intensity	45
Developed, High Intensity	14
Barren Land	7
Deciduous Forest	972
Evergreen Forest	13
Mixed Forest	104
Shrub/Scrub	2
Herbaceous	193
Hay/Pasture	775
Cultivated Crops	4122
Woody Wetlands	93
Emergent Herbaceous Wetlands	116
Total	6970

Table 7: Land Cover Class composition in the South East Lidar Acquisition Area Driftless Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

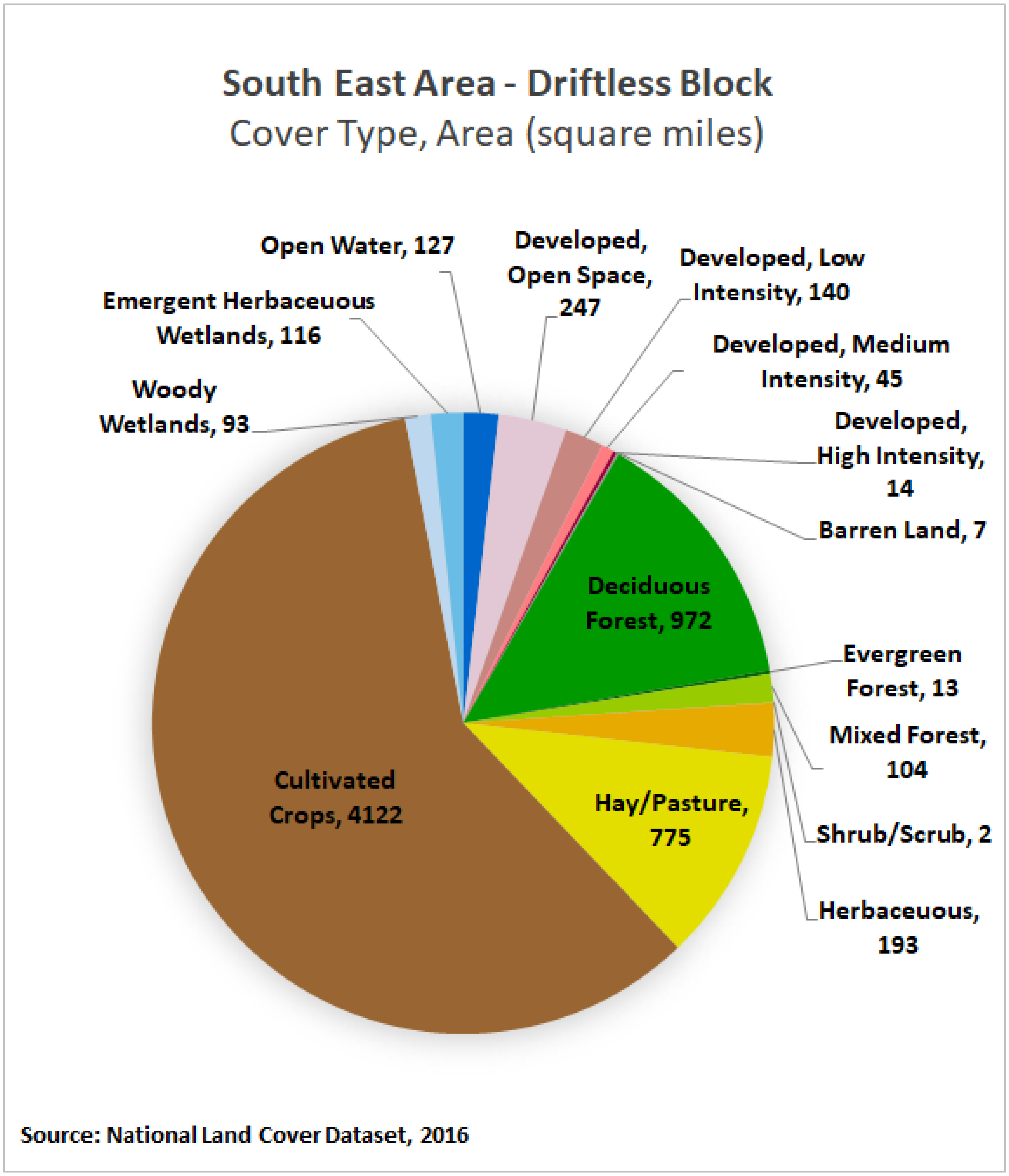

Figure 20: Land Cover Class composition in the South East Lidar Acquisition Area Driftless Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

South West Lidar Acquisition Area Missouri River Big Sioux Lidar Acquisition Block (LAB)

Land Cover Class	Area, square miles
Open Water	47
Developed, Open Space	113
Developed, Low Intensity	23
Developed, Medium Intensity	9
Developed, High Intensity	2
Barren Land	2
Deciduous Forest	9
Evergreen Forest	0
Mixed Forest	15
Shrub/Scrub	1
Herbaceous	113
Hay/Pasture	106
Cultivated Crops	2646
Woody Wetlands	1
Emergent Herbaceous Wetlands	82
Total	3169

Table 8: Land Cover Class composition in the South West Lidar Acquisition Area Missouri River Big Sioux Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

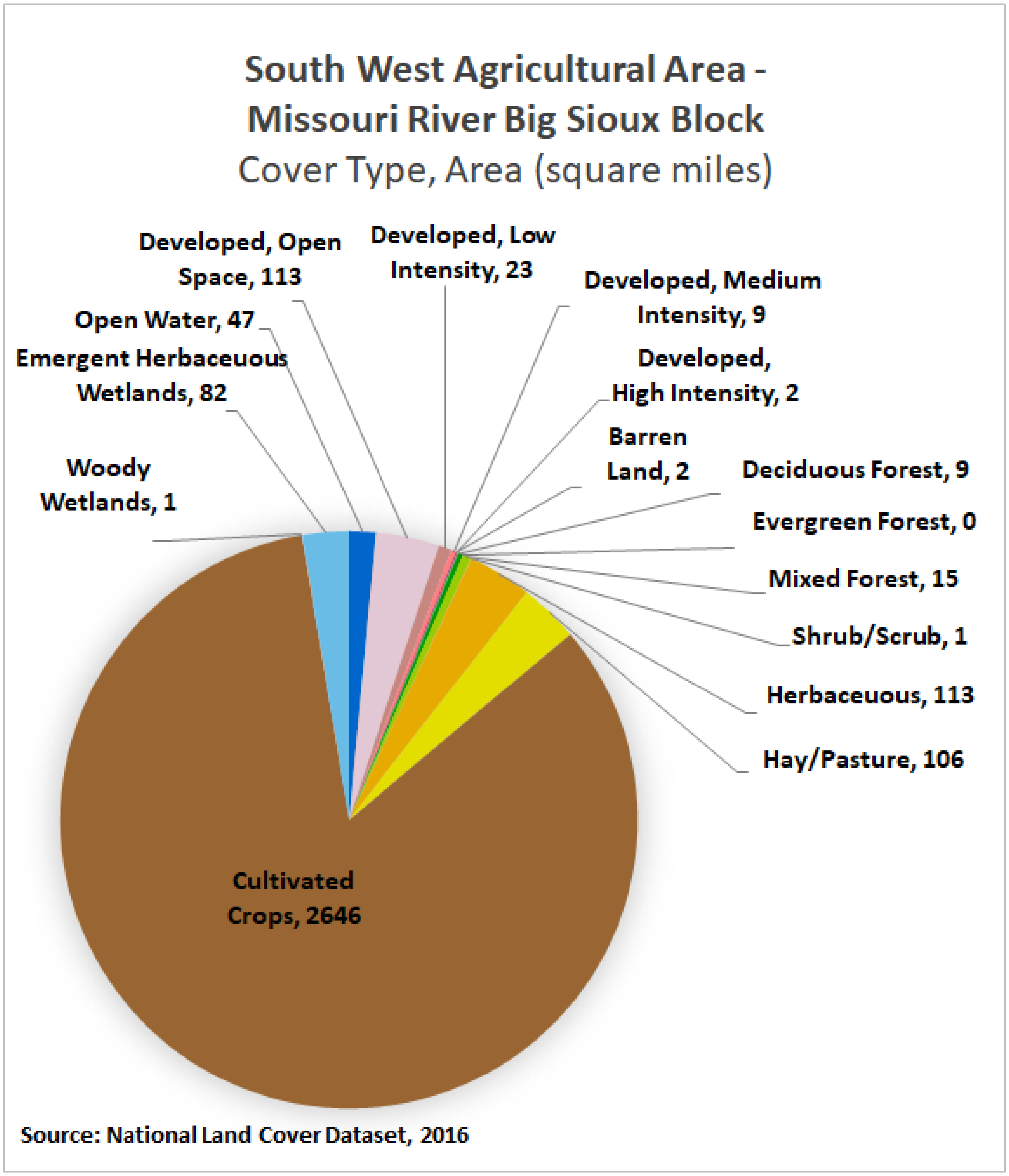

Figure 21: Land Cover Class composition in the South West Lidar Acquisition Area Missouri River Big Sioux Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

South West Lidar Acquisition Area East Lidar Acquisition Block (LAB)

Land Cover Class	Area, square miles
Open Water	140
Developed, Open Space	209
Developed, Low Intensity	74
Developed, Medium Intensity	29
Developed, High Intensity	9
Barren Land	12
Deciduous Forest	172
Evergreen Forest	0
Mixed Forest	12
Shrub/Scrub	1
Herbaceous	46
Hay/Pasture	142
Cultivated Crops	4979
Woody Wetlands	91
Emergent Herbaceous Wetlands	210
Total	6126

Table 9: Land Cover Class composition in the South West Lidar Acquisition Area East Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

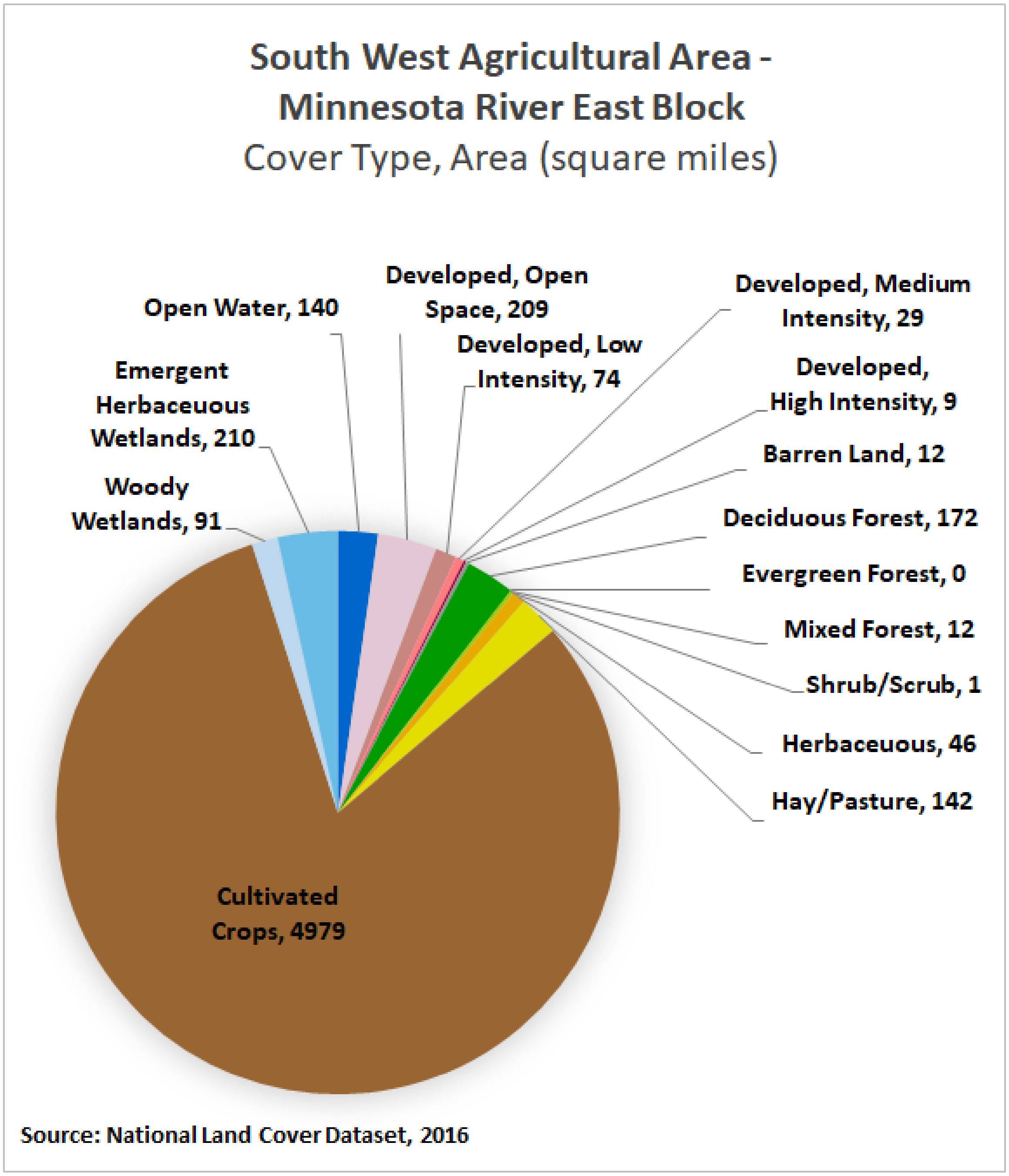

Figure 22: Land Cover Class composition in the South West Lidar Acquisition Area East Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

South West Lidar Acquisition Area West Lidar Acquisition Block (LAB)

Land Cover Class	Area, square miles
Open Water	376
Developed, Open Space	324
Developed, Low Intensity	79
Developed, Medium Intensity	26
Developed, High Intensity	7
Barren Land	14
Deciduous Forest	194
Evergreen Forest	3
Mixed Forest	49
Shrub/Scrub	2
Herbaceous	126
Hay/Pasture	543
Cultivated Crops	7268
Woody Wetlands	49
Emergent Herbaceous Wetlands	632
Total	9692

Table 10: Land Cover Class composition in the South West Lidar Acquisition Area West Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

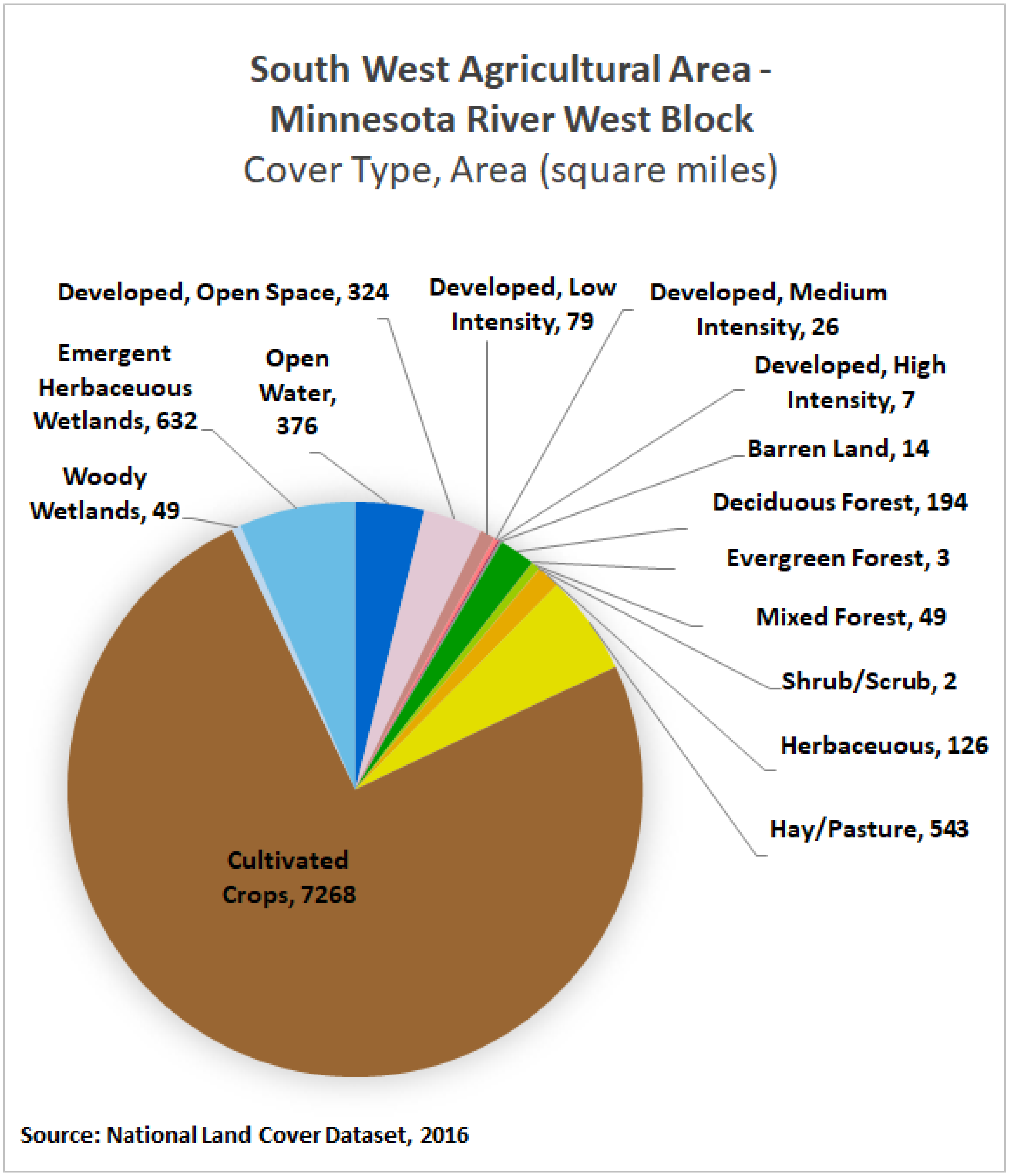

Figure 23: Land Cover Class composition in the South West Lidar Acquisition Area East Lidar Acquisition Block (LAB) and the corresponding area per class in square miles (source: National Land Cover Dataset (NLCD), 2016).

Appendix D: Document History

Date	Notes
10/3/2019	First Draft for internal review
10/21/2019	Reviewed by GIS and lidar contacts
10/24/2019	Provided to MNIT Communications for review and design
11/5/2019	Communications review completed
10/22/2021	Update to improved accessibility, remove draft status and update web links