



Environment and Natural Resources Trust Fund

2022 Request for Proposal

General Information

Proposal ID: 2022-072

Proposal Title: Merging lidar and satellite imagery for carbon estimation

Project Manager Information

Name: David Wilson

Organization: MN DNR - Forestry Division

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Project Basic Information

Project Summary: We will use lidar and Landsat data to provide spatially and temporally discrete estimates of biomass and carbon flux for disturbed and undisturbed forest landscapes.

Funds Requested: \$344,000

Proposed Project Completion: June 30 2025

LCCMR Funding Category: Air Quality, Climate Change, and Renewable Energy (E)

Project Location

What is the best scale for describing where your work will take place?

Statewide

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project and In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Minnesota's forests play a key role in providing natural climate solutions to combat climate change by absorbing carbon dioxide from the atmosphere and storing it as carbon in vegetation and soil. However, current forest inventories do not provide sufficient spatial and temporal resolution to accurately assess standing carbon stocks or their flux over time. Such estimates are needed to provide actionable information related to opportunities for greenhouse gas mitigation and carbon sequestration across Minnesota's rich natural resource landscape. High-density lidar data acquisitions, as part of implementing the Minnesota Statewide Lidar Plan, provide foundational forest inventory information when paired with plot based inventory (PBI) efforts. However, these data acquisitions can be expensive and are not frequently repeated. A temporal series of optical information (e.g., satellite and aerial photography) can extend the shelf life and utility of lidar. Open public access to satellite and lidar data may be particularly useful regarding estimation of forest characteristics across larger landscapes. This project will address the spatial and temporal challenges of forest inventory by combining PBI data with lidar and satellite remotely sensed data. This project will assess forest recovery for different types of disturbance agents and estimate carbon stock changes over time.

What is your proposed solution to the problem or opportunity discussed above? i.e. What are you seeking funding to do? You will be asked to expand on this in Activities and Milestones.

MNDNR Guideline Monitoring Program (GMP), as legislated in the Sustainable Forest Resources Act (SFRA) is continuously monitoring forest disturbance across Minnesota to identify sites where we evaluate forest management guideline (FMG) implementation. GMP is currently evaluating forest regeneration and biomass accumulation on sites monitored since 2000, using high density lidar and satellite imagery available for pilot areas in the Arrowhead region. This project will leverage recently developed forest inventory and modeling methods funded by the ENTRF in ML2016, emerging high density lidar data as part of the MN Lidar Plan, and continuously updated Landsat imagery based spectral indices to map status and changes in standing forest biomass and carbon stocks over time. Resulting models will estimate relevant forest characteristics on a wall-to-wall basis for landscapes where we have field and satellite data covering the time period of initial and high-density lidar acquisition through present day. We will develop a statewide map detailing above and below ground carbon stocks over time. Our focus will be on updates needed for portions of the landscape disturbed since acquisition of high-density lidar. These updates will help to ensure availability of the most accurate and relevant data related to carbon stocks and forest inventory priorities.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

Minnesota's 2007 Next Generation Energy Act and Executive Order 19-37 call for 80% reduction of statewide greenhouse gas emissions by 2050. To reach this goal, The Natural and Working Lands team of the Governor's Climate Change Subcabinet, created under EO 19-37, has identified the need to quantify the carbon storage benefits of Minnesota's lands and track changes over time. This project will expand and implement existing tools to enable monitoring of carbon fluxes on public and private lands so that potential carbon related impacts of management decisions can be quantified and outcomes can be measured.

Activities and Milestones

Activity 1: Remote Sensing Data Extraction and Compilation

Activity Budget: \$30,000

Activity Description:

Landsat data, including all needed spectral indices, are currently available via Google Earth Engine for the time period from 1974 to current day.

Remote sensing analysts at Resource Assessment currently have the needed expertise to extract all data needed for this project from the time series.

Statewide low-density lidar data were collected circa 2010, and have been compiled by Resource Assessment staff, including for areas where distribution or collection problems initially limited access to this data resource.

Thanks to projects supported by the ENTRF, USFS Superior National Forest, and MN DNR, high-density lidar has been acquired for three areas of interest in Cass and Lake Counties. These pilot acquisitions were paired with PBI field data collection to enable development of models for a variety of forest inventory metrics. High-density lidar data is now also available in Pine and Goodhue Counties, and acquisition plans are being finalized for much of the Arrowhead Region, as well as much of Southern Minnesota. PBI is being conducted on MN DNR managed lands in conjunction with these lidar collects to enable development of the full suite of desired forest inventory and remote sensing data products.

Substantial data management will be needed to support project outcomes.

Activity Milestones:

Description	Completion Date
Data compilation and plot-based extraction of values for Landsat indices.	September 30 2022
Data compilation and extraction of relevant metrics from statewide low-density lidar.	September 30 2022
Extraction of relevant metrics from models based on current and emerging high-density lidar.	March 31 2024

Activity 2: Model Development for Mapping of Forest Inventory and Carbon Resources

Activity Budget: \$120,000

Activity Description:

Remote sensing analysts and research scientists at MN DNR will work with the project manager to develop, refine, and implement machine learning models (e.g., randomForest) to produce spatially and temporally explicit estimates of forest conditions across Minnesota. Outputs will include above and below ground biomass and carbon stock estimations for baseline (2010) and current (2017-2021) timeframes. Models will be cross-validated using currently available high density lidar data and models, and refined as additional lidar and field data are collected statewide. Models may also be compared against Landsat only estimates incorporating FIA data as the ground truth.

Additional high density lidar data are anticipated for Rainy Lake, Lake Superior, SE and SW Minnesota, Central and Upper Mississippi River, and other landscapes prior to completion of this project. Partnerships with local foresters and resource managers are planned to provide both the lidar and PBI data needed for detailed modeling of forest attributes.

Activity Milestones:

Description	Completion Date
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Development and refinement of initial above ground biomass, timber volume, and canopy height models.	December 31 2022
Development of initial maps for pilot high-density lidar areas of interest.	March 31 2023
Cross validation of model output for plots and stands of various ages and species composition.	June 30 2023

Activity 3: Incorporation of large-scale high-density lidar and plot-based inventory data.

Activity Budget: \$50,000

Activity Description:

As high-density lidar and plot-based forest inventories are collected and made available for the Rainy Lake, Superior, Southeast, and other landscapes, we will further calibrate and refine our models to better estimate forest characteristics and carbon stocks across the state. This process will require an iteration over Activities 1 and 2, incorporating substantially larger amounts of data from these new acquisitions to inform model outcomes. Current plans for PBI collection cover only MN DNR managed lands, so resulting models will be most relevant to forest lands representative of those parcels. Collection of PBI data on other ownerships, concurrent with high density lidar acquisition, would extend the relevance of the models to encompass additional variability likely present across the larger landscape. Outside the boundaries of high-density lidar acquisitions, forest biomass and carbon will be mapped based on models integrating FIA data with low-density lidar and Landsat variables.

Activity Milestones:

Description	Completion Date
Acquisition and development of forest inventory models from emerging high-density lidar landscapes.	March 31 2024
Extraction of relevant lidar and lidar-based model indices from emerging data sources.	March 31 2024
Incorporation of large-scale high-density lidar data to inform statewide models	April 30 2024
Cross-validation of large-scale models prior to statewide map production	September 30 2024

Activity 4: Statewide Map Production for Modeled Forest Attributes (Carbon, Biomass)

Activity Budget: \$70,000

Activity Description:

Following initial model development, incorporation of emerging large-scale lidar and plot-based forest inventory data, model refinement, and final cross-validation, it will become possible to produce maps of modeled forest attributes statewide. Results will be most pertinent to landscapes used in model development, but should be generalizable to the extent that input data is representative of the range of forest conditions present across the state. Additional forms of accuracy assessment will also be completed at this stage to characterize the applicability of resulting maps to forests statewide (all ownerships), including comparison with Landsat only model results. Final statewide maps include wall-to-wall representations of above and below ground biomass and carbon stocks for the baseline (2010) and current (dependent on the most recent dates of high density lidar collection) timeframes. These maps will be updateable based on relationships defined in the modeling process, and using spectral indices provided by Landsat on an annualized basis.

Activity Milestones:

Description	Completion Date
Statewide Map of Above Ground Biomass (2010 and 2021)	April 30 2025
Statewide Map of Below Ground Biomass (2010 and 2021)	April 30 2025
Statewide Map of Forest Carbon Stocks (2010 and 2021)	April 30 2025
Final Accuracy Assessment	April 30 2025

Activity 5: Comparison of Carbon Flux within GEE Change and Control Polygons

Activity Budget: \$10,000

Activity Description:

Forest disturbance areas (change polygons) mapped by GMP using Google Earth Engine (GEE) methods for years corresponding to the acquisitions of statewide low and high density lidars will be intersected with biomass and carbon maps for the two periods to estimate carbon flux over time for forest subjected to different disturbance agents, and undisturbed sites. Field data collected by GMP on monitored harvest sites will be used to validate model accuracies for harvested conditions. We will also develop a set of control polygons for undisturbed locations not represented in the 46 year series of forest canopy change developed from Landsat. Separate subsets of these control polygons will be used to inform the model and to test the accuracy of carbon estimates for mature forest.

Activity Milestones:

Description	Completion Date
Development of non-change (control) site polygon layer.	December 31 2022
Extraction of change polygons for lidar collection dates (years).	March 31 2023
Extraction of Zonal Statistics (biomass and carbon) for change and control polygons	December 31 2024
Statistical comparison of carbon flux for disturbed and undisturbed sites.	March 31 2025

Activity 6: Distribution of Project Results (Publications and Maps of Forest Carbon and Biomass)

Activity Budget: \$30,000

Activity Description:

Project results will be reported to LCCMR and subsequently written up for publication submission to a peer reviewed journal to be determined. Outreach and education webinars will be held and project information will be shared widely throughout the forestry community through a number of state and regional avenues already established by the project team. Resulting maps of forest resources and characteristics will be made available to MN DNR staff via the Minnesota Geospatial Data Commons. The project team will also work with additional stakeholders through the Minnesota Geospatial Advisory Council's 3DGeomatics Committee to find appropriate web hosting services for public distribution of the data and maps.

Activity Milestones:

Description	Completion Date
Final Report to LCCMR	June 30 2025
Submission of Map Service to GDRS for use by DNR Staff	June 30 2025
Coordination with Stakeholders to Make Maps Publicly Available on the Internet	June 30 2025
Submission of Manuscript to Peer Reviewed Journal	June 30 2025

Activity 7: Project Management, Consulting, and Reporting

Activity Budget: \$34,000

Activity Description:

The project manager will be responsible for coordinating the project team, overseeing the full suite of project activities over the three year lifespan of the project and for integrating results into reports to LCCMR, peer reviewed journals, and other outlets.

Activity Milestones:

Description	Completion Date
Assemble project team and contract with Resource Assessment for professional Services	July 31 2022
Coordinate Activities 1 - 6 to ensure project completion within budget and timeframe	June 30 2025
Project Reporting to LCCMR and Peer Reviewed Journal	June 30 2025

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Lucas Spaete	Minnesota DNR - Forestry, Resource Assessment	Lucas manages an array of projects focused on the assessment of Minnesota's forests, wetlands, and other natural communities. Lucas also serves as a lead Remote Sensing Analyst for the Resource Assessment Unit of the Division of Forestry. Lucas has specialized experience working with satellite imagery and lidar data.	Yes
Ram Deo	Minnesota DNR - Forestry, Resource Assessment	Ram holds a PhD in forestry and remote sensing, and currently serves as the lead lidar analyst and modeler for the Division of Forestry's Resource Assessment Unit. Ram has played an integral role in developing the current paradigm for using lidar and plot based inventory to model Minnesota's forest resources.	Yes
Jennifer Corcoran	Minnesota DNR - Forestry, Resource Assessment	Jennifer is the Remote Sensing Program Consultant for the Division of Forestry's Resource Assessment Unit. In this capacity, Jennifer is responsible for planning, organizing, acquiring funding, and broadly managing all aspects of Minnesota's world-class remote sensing and data acquisition efforts.	Yes

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this be funded?

Results will be implemented via distribution on a web-based raster image service accessible to resource managers and the public. Currently, Minnesota DNR is capable of hosting such a service for use by internal staff. Both Resource Assessment and other stakeholders are actively working to develop needed systems to provide public access to fundamental natural resource data and information. These web-based systems will facilitate public and private planning for air quality, climate change, wildlife habitat, and renewable energy projects. It is assumed that Resource Assessment would lead future efforts to update project results.

Project Manager and Organization Qualifications

Project Manager Name: David Wilson

Job Title: Natural Resource Program Consultant - Guideline Monitoring

Provide description of the project manager's qualifications to manage the proposed project.

David Wilson holds a M.S. in Geographic Information Systems Science and a PhD in Natural Resource Science and Management (forest biology, ecology, and management). David has 16 years of experience applying spatial and relational data techniques to analyze, quantify, and plan for the management of natural resources. David also has 10 years of experience working with forest biometrics data, statistical analysis of natural resources data (esp. forest inventory) and developing spatial and statistical models from field-based and remotely sensed data. Examples include: 1) development of forest connectivity models quantifying the potential for management of forest habitat for area sensitive and forest interior migratory bird species, 2) examination of USDA-Forest Service Forest Inventory and Analysis (FIA) data with respect to trends in Minnesota's moose herd to identify generally aging forests as a possible contributor to the decline of the population, 3) quantification of the potential to sustainably utilize forest biomass to offset fossil fuels used to generate electricity in Minnesota and the Upper Lake States Region, 4) examination of forest disturbance trends in Minnesota via FIA plot observations (1999-2018), 5) development of a machine learning algorithm and associated methods to infer native plant community classifications for forest inventory plots and stands in Minnesota, 6) examination and development of forest regeneration models and biomass accumulation rates on stands harvested since

2000 using lidar and Landsat remotely sensed data (Arrowhead Region).

David has extensive project management experience, ranging from coordination of the Upper Mississippi Basin Stakeholders Network and the Driftless Area Initiative to managing the 2014 re-inventory of forest resources at the University of Minnesota's Cloquet Forestry Center. David's current post is with the Minnesota Department of Natural Resources as a Natural Resource Program Consultant managing the Forest Management Guideline Monitoring Program for the Division of Forestry.

Organization: MN DNR - Forestry Division

Organization Description:

The Minnesota Department of Natural Resources (DNR)'s mission is to work with citizens to conserve and manage the state's natural resources, to provide outdoor recreation opportunities, and to provide for commercial uses of natural resources in a way that creates a sustainable quality of life.

The Division of Forestry's mission is to provide a shared expertise to understand, sustain, and manage Minnesota's trees, woodlands, and forests; provide a sustainable supply of multiple forest resources and opportunities; Protect lives and property from wildfires; and fulfill responsibilities to the permanent school trust.

The Resource Assessment Program (RAP) supports Division of Forestry and DNR goals to maintain and improve the health of Minnesota's forests and natural resources. RAP provides natural resource managers with critical support for decision-making by providing; expertise in natural resource field inventory, aerial photography, spatial analysis, remote sensing analysis, including lidar and satellite image processing. These products and services are critical in supporting management of forest health, timber yields and wildlife, among other uses. The rich data and analysis are important to help deal with the effects of widely variable forest change patterns, invasive species and disease, disruptive forest events, and many other impacts of climate change.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	\$ Amount
Personnel								
Natural Resource Program Consultant		Project Manager / Consultant			17%	0.15		\$30,000
							Sub Total	\$30,000
Contracts and Services								
MNDNR Forestry, Resource Assessment	Professional or Technical Service Contract	All actions outline in this proposal will be completed by Resource Assessment personnel. Actions include data acquisition and management, model development, model validation, final map production, and management of the project team.				5.26		\$310,000
							Sub Total	\$310,000
Equipment, Tools, and Supplies								
							Sub Total	-
Capital Expenditures								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-
Travel In Minnesota								
							Sub Total	-

Travel Outside Minnesota								
							Sub Total	-
Printing and Publication								
							Sub Total	-
Other Expenses								
		Direct and Necessary People Support	Human Resources Management					\$250
		Direct and Necessary Safety Support	Safety Training for Necessary Personnel					\$50
		Direct and Necessary IT Support	Information Technology Support for Project					\$800
		Direct and Necessary Communications Support	Communications among project team members and organizational management					\$1,300
		Direct and Necessary Financial Management Support	Support for project accounting.					\$500
		Direct and Necessary Planning Support	Support for financial planning of allotments					\$1,100
							Sub Total	\$4,000
							Grand Total	\$344,000

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
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Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	-
Non-State				
			Non State Sub Total	-
			Funds Total	-

Attachments

Required Attachments

Visual Component

File: [c54fa34c-87c.pdf](#)

Alternate Text for Visual Component

Map showing statewide progress and planning for high-density lidar data acquisition....

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have potential for royalties, copyrights, patents, or sale of products and assets?

No

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

N/A

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

N/A

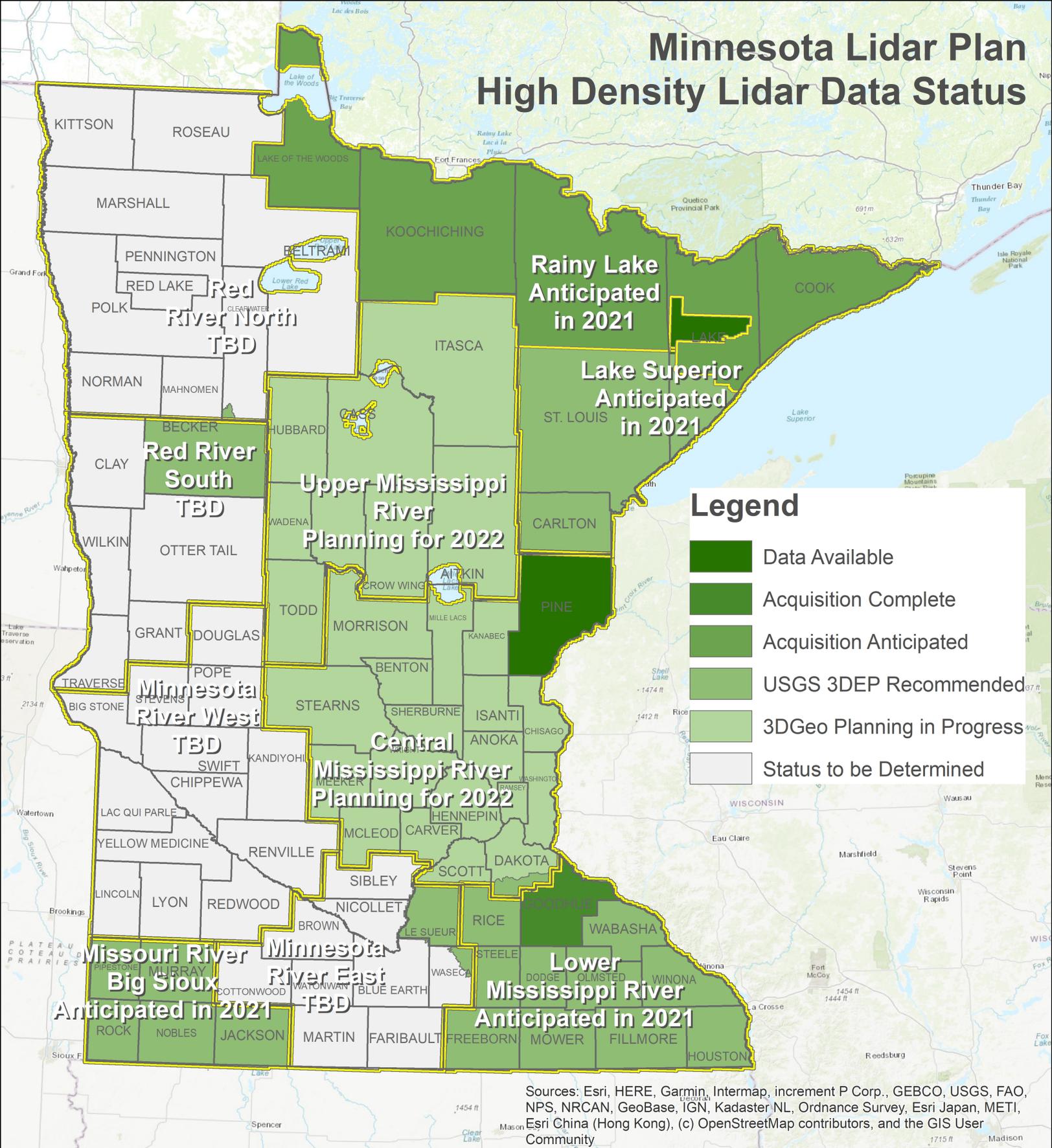
Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

No

Minnesota Lidar Plan High Density Lidar Data Status



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

2021 contracts are underway. All other areas are pending partnerships and funding.



Map Date: Feb 12, 2021