MINNESOTA
CLEAN WATER COUNCIL

Assessment of the Implementation of High-Resolution Digital Elevation Data Developed through Light Detecting and Ranging (Lidar)

January 2022

Legislative Charge

This report is required by the Legacy Finance appropriation in 2021 Session Laws, chapter 1, article 2, section 24:

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Summary

The Legislature appropriated $8.3 million from the Clean Water Fund in 2009 and 2011 for high resolution digital elevation data developed through the use of Light Detecting and Ranging (Lidar). In response to a Legislative request for a report on this appropriation, the Clean Water Council finds the following:

- This data and resulting work products have advanced Minnesota's efforts to protect and restore surface waters and groundwater.
- These activities are consistent with the statutes governing the Clean Water Fund.
- Digital elevation data have saved countless hours of labor for water managers while enabling the targeted use of finite financial resources where it will do the most good for water quality.
- Lidar increased the likelihood of success for protection and restoration projects.
- Lidar data assist with compliance efforts, including accurate mapping of required riparian buffers.
- Without this Lidar appropriation, projects to achieve water quality goals would have been less effective or more costly during the last decade, or may not have happened at all.

Legislative Charge

In its 2021 budget appropriation for the Clean Water Fund, the Minnesota Legislature directed the Clean Water Council to report on the use of high-resolution digital elevation data supported by the Clean Water Fund in 2009 and 2011.

> 2021 Session Laws, chapter 1, article 2, section 24: **CLEAN WATER COUNCIL; REPORT REQUIRED.**
>
> By January 15, 2022, the Clean Water Council must submit a report to the chairs and ranking minority members of the house of representatives and senate committees and divisions with jurisdiction over the environment and natural resources and legacy that includes an assessment of the implementation of the high-resolution digital elevation data developed with the appropriations in Laws 2009, chapter 172, article 2, section 5, paragraph (d), and Laws 2011, First Special Session chapter 6, article 2, section 6, paragraph (h).

The relevant statutes from 2009 and 2011 read as follows:

> 2009 Session Laws, chapter 172, article 2, section 5, paragraph (d)
>
> (d) $2,800,000 the first year and $2,800,000 the second year are to acquire and distribute high-resolution digital elevation data using light detection and ranging to aid with impaired waters modeling and total maximum daily load implementation under Minnesota Statutes, chapter 114D. The data will be collected for areas of the state that have not acquired such data prior to January 1, 2007, or to complete acquisition and distribution of the data for those areas of the state that have not previously received state funds for acquiring and distributing the data. The distribution of data acquired under this paragraph must be conducted under the auspices of the Land Management Information Center or its successor, which shall receive 2.5 percent of the appropriation in this paragraph to support coordination of data acquisition and distribution. Mapping and data set distribution under this paragraph must be completed within three years of funds availability. The commissioner shall utilize department staff whenever possible. The commissioner may contract for services only if they cannot otherwise be provided by the department. If the commissioner contracts for services with this appropriation and any of the work done under the contract will be done outside of the United States, the commissioner must report to the chairs of the house of representatives and senate finance committees on the proposed contract at least 30 days before

entering into the contract. The report must include an analysis of why the contract with the selected contractor provides the state with "best value," as defined in Minnesota Statutes, section 16C.02; any alternatives to the selected contractor that were considered; what data will be provided to the contractor, including the data that will be transmitted outside of the United States; what security measures will be taken to ensure that the data is treated in accordance with the Minnesota Government Data Practices Act; and what remedies will be available to the state if the data is not treated in accordance with the Minnesota Government Data Practices Act.

2011 Session Laws, First Special Session, chapter 6, article 2, section 6, paragraph (h).

(h) $1,350,000 the first year and $1,350,000 the second year are to acquire and distribute high-resolution digital elevation data using light detection and ranging to aid with impaired waters modeling and TMDL implementation under Minnesota Statutes, chapter 114D. The money shall be used to collect data for areas of the state that have not acquired the data prior to January 1, 2007, or to complete acquisition and distribution of the data for those areas of the state that have not previously received state funds for acquiring and distributing the data. The distribution of data acquired under this paragraph must be conducted under the auspices of the Minnesota Geospatial Information Office, which shall receive up to 2.5 percent of the appropriation in this paragraph to support coordination of data acquisition and distribution. Mapping and data set distribution under this paragraph must be completed within three years of funds availability. The commissioner shall utilize department staff whenever possible. The commissioner may contract for services only if the services cannot otherwise be provided by the department.

Area Covered

The areas covered by the 2009 and 2011 appropriations included approximately 40,000 square miles in the following areas:

- Minnesota River basin
- Twin Cities metro area
- Lake Superior basin
- Mississippi River basin

These Clean Water Fund appropriations did not support Lidar in areas of the state that had other funding sources, including the Red River basin, counties affected by flooding in southeastern Minnesota in 2007, and seven counties that acquired data on their own.

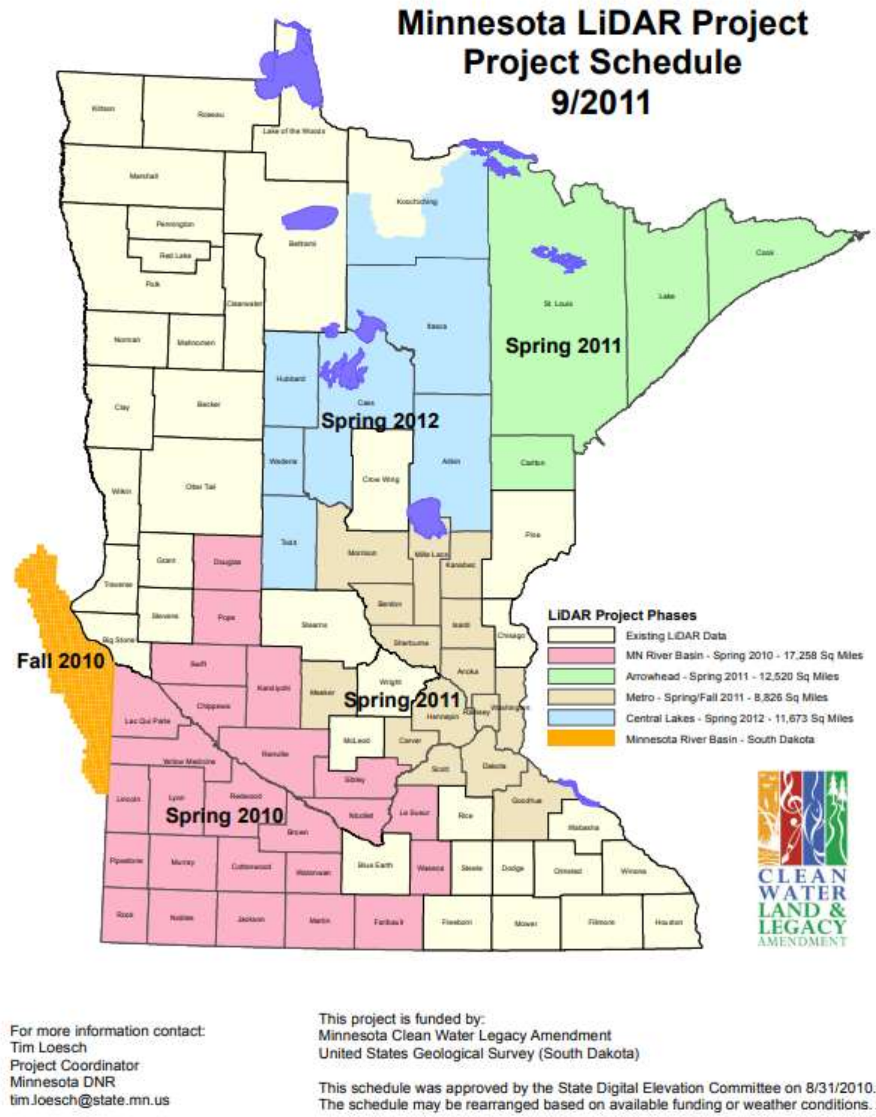

Figure 1: Map Showing Areas Covered by Clean Water Fund Lidar Appropriation

By "filling in the gaps" to create a state wide data set, there has been consistency across watersheds, which do not respect political boundaries. Minnesota's water planning and strategy development focuses on HUC-8 scale watersheds, of which there are 80 across the state.

Figure 2: Basins and Watersheds in Minnesota

How Elevation Data Are Used

Lidar generates high resolution elevation data. The resolution of Lidar technology at the time of acquisition ten years ago had horizontal accuracy of one meter and vertical accuracy of 15 centimeters.

The Lidar data set acquired in 2009 and 2011 is the foundational “base layer” of information. Data managers throughout government can develop additional data layers from the Lidar data for specific purposes, but the digital elevation data remains the same.

Local government partners, such as counties, soil and water conservation districts (SWCDs), watershed districts (WDs), watershed management organizations (WMOs), and cities, along with the United States Department of Agriculture Natural Resource Conservation Service (USDA-NRCS), the private sector and higher education institutions, utilize Lidar data on a daily basis to meet their business need for water quality restoration and protection work, along with water quantity and flood control projects. Lidar is a crucial dataset for professional staff working in the agricultural, forested, and urban areas of the state.

The examples below are some of the ways in which the foundational Lidar dataset has been used to advance efforts to address water resources issues in Minnesota.

Public Access through MnTOPO Website:

The Lidar data compiled through the 2009 and 2011 Clean Water Fund appropriation is administered by the Minnesota Geospatial Information Office (MnGeo) at Minnesota IT Services (MNIT).

The state of Minnesota through the Minnesota Department of Natural Resources (MN DNR) has provided a web application, [MnTOPO, for users]to publicly view, print, or download the high resolution Lidar data[maintained by MnGeo]. This application is essential for any professional and citizen that needs to have directly access to the publicly available data. MnTOPO provides both a rich on-screen web-based viewing environment as well as access to the raw, or unprocessed, Lidar data and several ready-made Lidar data products, such as contours. The user download ready-made products, or the raw data that they can then transform and analyze to develop their own derived products that inform decision making.

MnGeo has tracked downloads of data from MnTOPO and through direct file transfer protocol (FTP) downloads since 2013. A summary of the number of Lidar downloads from MnTOPO is below. The reader will note that the contour data alone have been downloaded more than 42,000 times. In addition to the MnTOPO downloads shared below, MnGeo reports that thousands of Lidar files are downloaded directly by FTP each year as well.

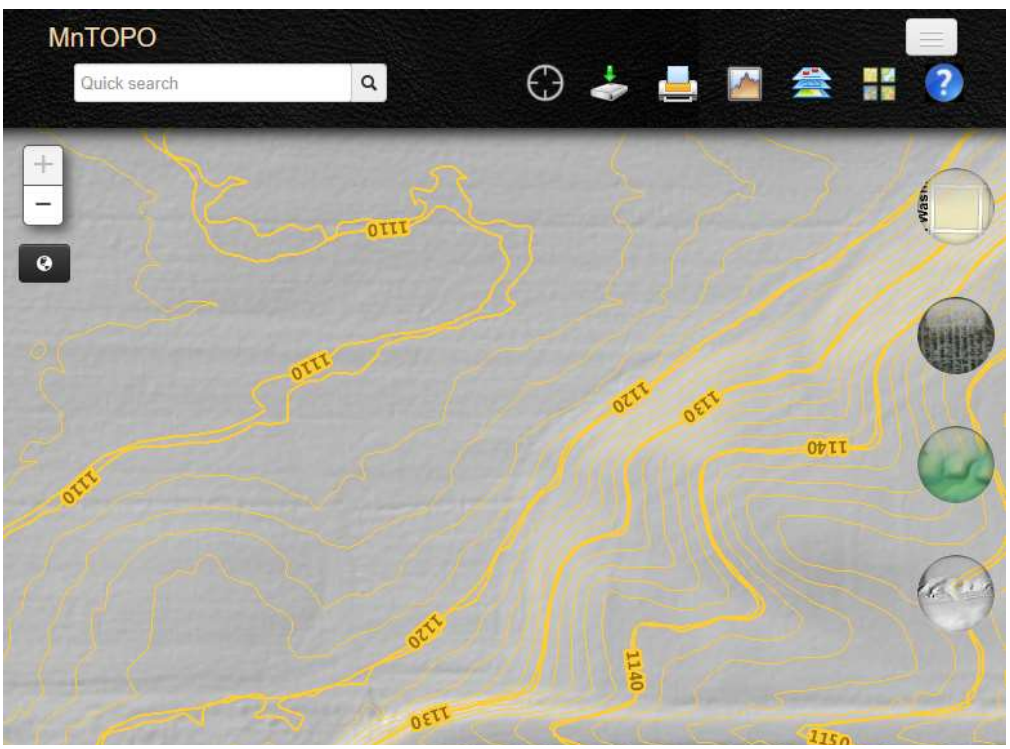

Figure 3: Example of Contour Map Available from MnTOPO

Table 1: Number of Data Downloads via MnTOPO

Minnesota Lidar Data **Number of data downloads via MnTOPO**											
		Dataset downloaded									
Year	**format**	**laz**	**bare earth**	**buildings**	**contours**	**dem01**	**dem03**	**dem01hs**	**dem03hs**	**breaklines**	
individual data downloads - all years (2013 to 10/2021)	open	4,850	2,924	3,403	20,563	6,099	1,451	1,638	643	2,400	3,669
individual data downloads - all years (2013 to 10/2021)	gdb	8,705	3,246	5,199	21,830	15,802	5,966	6,526	2,586	2,980	8,804
individual data downloads - all years (2013 to 10/2021)	**total**	**13,555**	**6,170**	**8,602**	**42,393**	**21,901**	**7,417**	**8,164**	**3,229**	**5,380**	**12,473**

Source: MnGeo

Legend

Term in spreadsheet	Definition
Laz	The unprocessed (or raw) Lidar point cloud dataset which includes all 3D points. The “laz” refers to the compressed format (.laz) of the raw point cloud format (.las). LAZ files are about 10 times smaller than the source data which accommodates data storage and dissemination by using less hardware space and less bandwidth during data sharing operations.
bare earth	Those 3D points extracted from the raw Lidar point cloud classified with a unique value that represents ground. These points are free from vegetation, buildings, and other man-made structures.
Buildings	A polygon dataset representing the outlines (i.e., footprints) of buildings extracted from the raw Lidar point cloud
Contours	Lines of equal elevation defining the terrain of earth’s surface with 2-foot intervals of elevation. These contours were created from the 1-meter digital elevation model.

Term in spreadsheet	Definition
dem01	A digital representation of the terrain or topographic surface of the earth called a digital elevation model (DEM). It is created from the classified bare earth Lidar points to represent landscape detail at one square-meter of resolution.
dem03	A digital representation of the terrain or topographic surface of the earth called a digital elevation model (DEM). It is created from the classified bare earth Lidar points to represent landscape detail at three square-meters of resolution.
dem01hs	A hillshade of the 1-meter digital elevation model (DEM). A hillshade provides a 3D perspective to the DEM by giving the minds-eye sunlight shinning from west to east with shadows being cast on the downside of peaks and valleys.
dem03hs	A hillshade of the 3-meter digital elevation model (DEM). A hillshade provides a 3D perspective to the DEM by giving the minds-eye sunlight shinning from west to east with shadows being cast on the downside of peaks and valleys.
Breaklines	Breaklines are delineated lines that represent a sharp change in elevation. Breaklines are used in creation of the digital elevation model (DEM) to maintain sharp changes in elevation during the mathematical interpolation process. Most of the breaklines downloadable from MnTOPO represent hydrography breaklines which define the banks of lake, wetland, and watercourse features.

Download Format

Term in spreadsheet	Definition
Open	Refers to an open-source text-based data format that can be used with various GIS and image processing software pa proprietary formatting.
Gdb	Refers to a proprietary GIS file geodatabase format for use with Esri brand GIS software packages

Hydro-modification of Digital Elevation Models (hDEM):

One of the most valuable Lidar-derived products is the development of hydro-modified digital elevation models, or hDEMs. Technicians need to modify Lidar-derived digital elevation models (DEM) data to establish the subsurface flow of water connectivity through landscape features like bridges and culverts that act as impediments in the DEM surface. These impediments otherwise appear to be “digital dams” in the DEM that would keep planners from seeing how water flows accurately within a watershed. This work creates a DEM that is hydrologically connected and that can be used in watershed models such as the Prioritize Target Measure Application (PTMApp), Agricultural Conservation Planning Framework (ACPF), Gridded Surface/Subsurface Hydrologic Analysis (GSSHA), and the Soil Water Assessment Tool (SWAT). For watershed models to function properly, model runoff and watershed loads, and in the case of PTMApp and ACPF site best management practices (BMPs), having a proper hDEM as a model input is necessary.

BWSR has been working with the MN DNR/MNIT to capture and store these breech lines (ex. culvert, bridge locations) and hDEM datasets. A pilot project has been underway with St. Mary’s University to develop a web application to view locations of the breech line data.

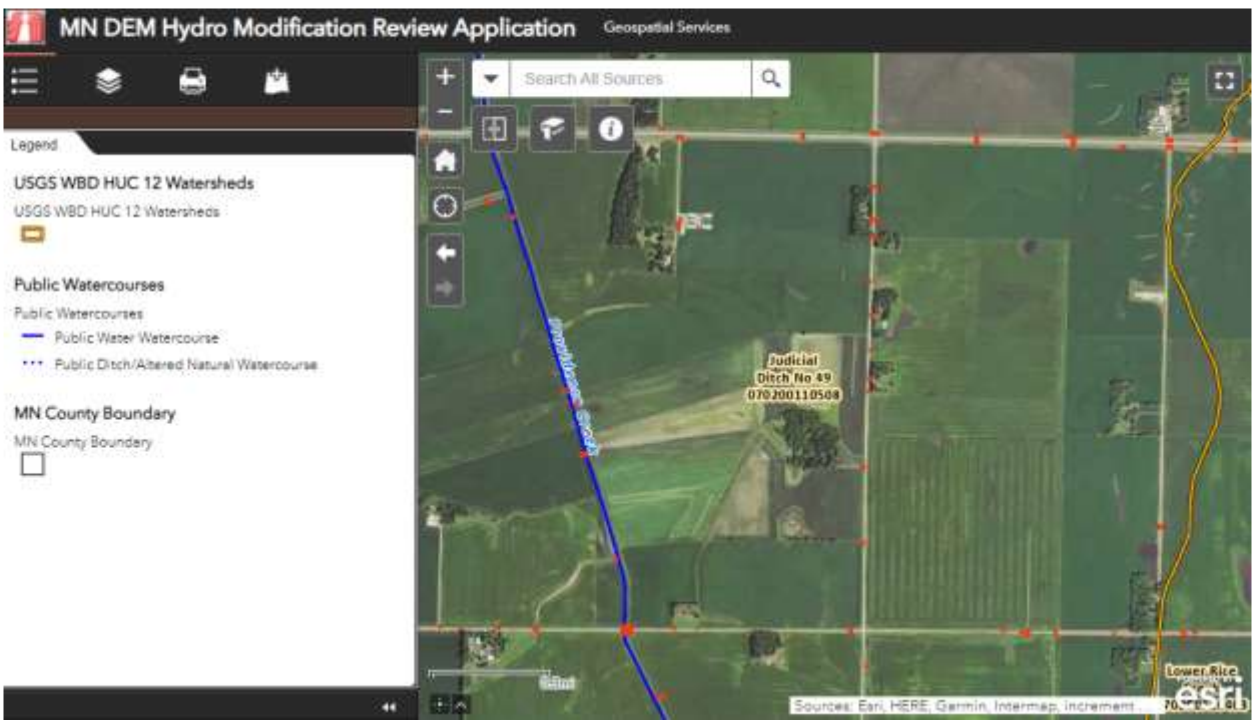

Figure 4: Breech Lines Shown in Red

Prioritize Target Measure Application (PTMApp) and Terrain Analysis Products:

BWSR has been working with local partners and project collaborators to develop the PTMApp model. The model assesses the impacts of sediment, phosphorus, and nitrogen to water resources, evaluates scenarios on how to address these pollution concerns, and assists in siting practices that are cost effective and will help meet watershed reduction goals. PTMApp development ensued after the initial Lidar was collected in the Red River basin. This work was led by the International Water Institute. The initial Lidar collect was essential to PTMApp model development as an hDEM is a required input for the tool. Improved and enhanced versions of PTMApp support the One Watershed One Plan process as well as local practitioners implementing projects on the ground. A [web application](#) has been developed to provide public access to PTMApp data. This model has been applied in many watersheds of Minnesota and is also being used in the neighboring states of North Dakota, Iowa, and Wisconsin by watershed planners.

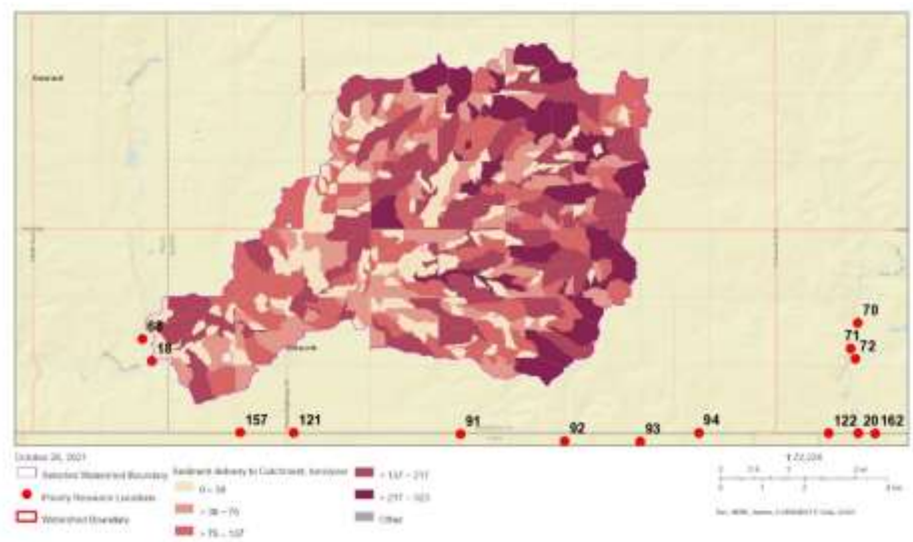

Figure 5: Example of PTMApp outputs showing the sediment delivery within a sub-watershed.

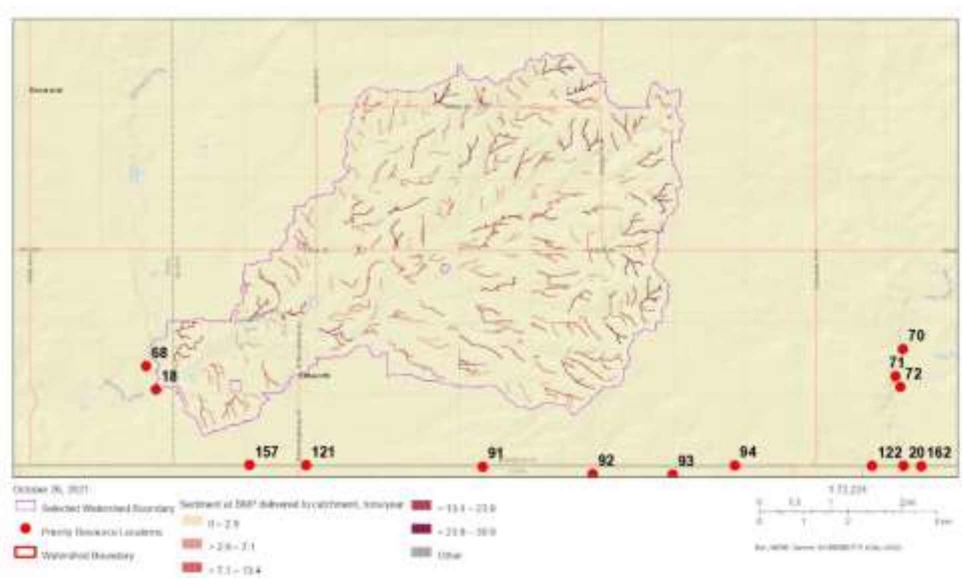

Figure 6: Example of PTMApp data outputs showing placement of BMPs and their impact of sediment loss.

PTMApp and ACPF models help create terrain analysis products. One common dataset created is a stream power index (SPI) layer (see example below) developed from the hDEM that is helpful in illustrating the flow network across watersheds. The SPI shows planners where erosion is more likely due to higher slopes and flow accumulation.

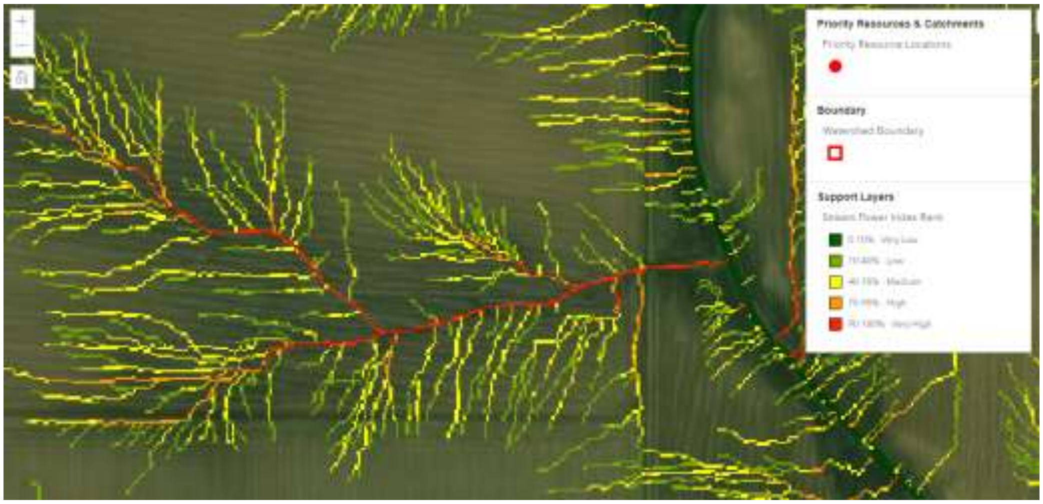

Figure 7: Example of Stream Power Index capability

Daily Erosion Project (DEP):

The [Daily Erosion Project (DEP)]() application, which is based on the Water Erosion Prediction Project model (WEPP), estimates soil erosion, water runoff, and soil moisture for most of Minnesota's agricultural region. In each HUC12 sub-watershed, the DEP web app shows an interactive map with data for daily precipitation, water runoff, soil detachment, and hillslope soil loss. The data from the current day is available the following day and can be exported in tabular and geospatial formats. The DEP was expanded to the State of Minnesota under the umbrella of the [Tillage and Erosion Project]() that is managed by BWSR and funded through the Clean Water Fund. BWSR contracts with the University of Minnesota Soil Water Climate Department (U of M) and Iowa State University (ISU) to maintain and update the DEP. Lidar is a critical piece of the DEP and an automated hDEM was developed for the State through machine learning techniques developed by ISU. The data allow planners to identify areas on the landscape where BMPs can be placed that can reduce erosion in the future.

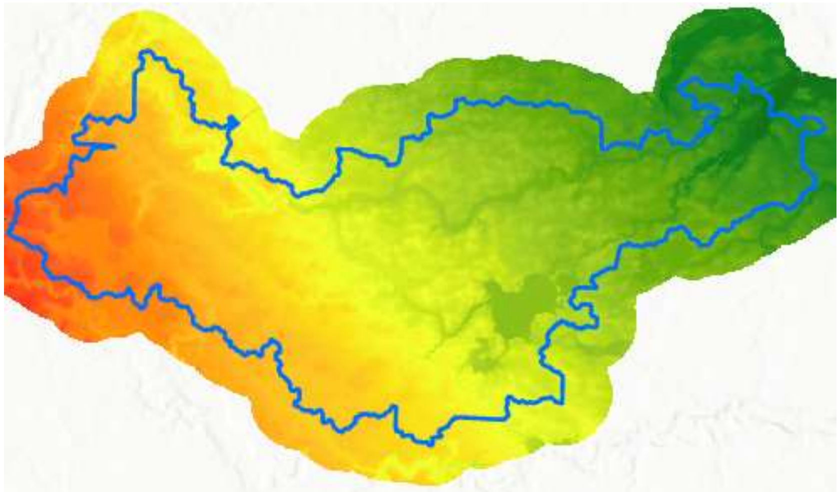

Figure 8: Example of an automated hDEM for a sub-watershed in Minnesota:

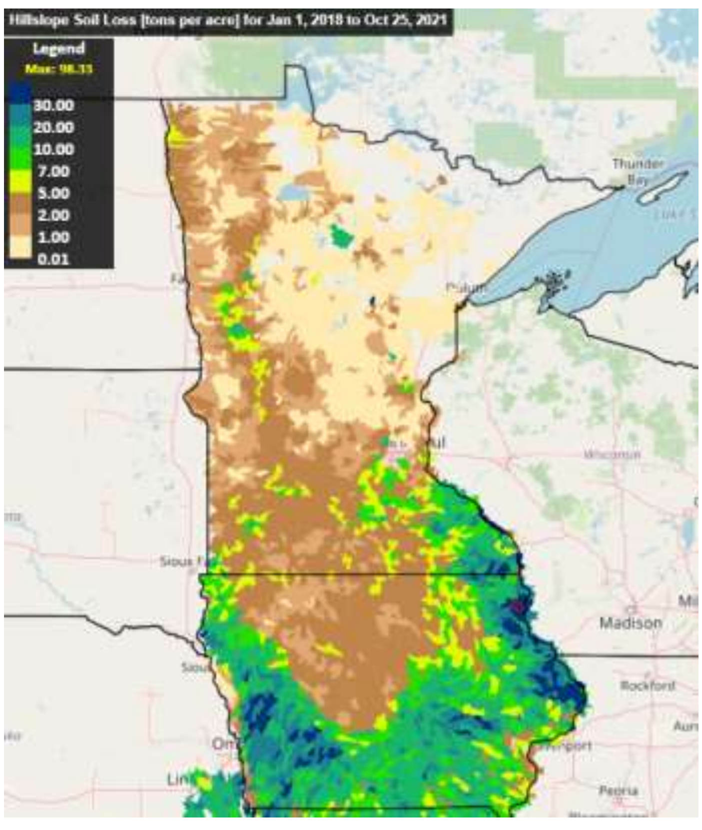

Figure 9: DEP output showing hillslope soil loss across Minnesota and Iowa from 2018-2021.

Agricultural Conservation Planning Framework (ACPF):

The ACPF is another tool that assists site conservation practices and local planning efforts. Using Lidar and an hDEM, ACPF assists practitioners in implementing field scale BMPs using terrain analysis. The ACPF was originally developed by the United State Department of Agriculture Agricultural Research Service (USDA-ARS). This model has been run on several sub-watersheds primarily in southern Minnesota. The underlying databases (field boundaries, soils, crop rotations) have been developed for Minnesota through the Daily Erosion Project work and are maintained by ISU.

Figure 10: ACPF output map showing potential locations of water and sediment control basins (WASCOBs).

Buffer Compliance and Tracking (BuffCAT):

BuffCAT is the Buffer Compliance and Tracking tool developed by BWSR/MNIT. SWCDs use BuffCAT to monitor and report on compliance with Minnesota's Riparian Protection Law/Buffer Law. SWCD staff use multiple layers of this GIS-based tool to make a preliminary remote assessment of a parcel before needing to go into the field. Lidar-derived products such as Hill Shade and Hydrographic Position Index allow SWCD staff to assess "top of bank" locations to confirm that buffers are a sufficient width. BuffCAT has saved countless hours of local staff time for site assessments and speeds up compliance monitoring.

Engineering and Design of BMPs:

Lidar elevation data allow designers to complete preliminary engineering designs and estimates with fewer site visits and surveys. Local, state, and federal decision makers can decide the merits of a project before investing significant staff time. Staff can also gather otherwise inaccessible topographic information (e.g., cropland during the growing season, snow covered areas during the winter).

BWSR staff use Lidar on every wetland design project. Since 2015, Lidar has been used to help with design on 439 projects. The agency estimates that each project saves approximately 12 staff hours, so nearly 5,300 staff hours have been saved by using Lidar data on wetland restoration projects.

The USDA-NRCS has well documented the uses for Lidar within [Technical Note 210-SRVN-01](). The University of Minnesota specifically developed and tailored Lidar [training materials](), workshops, and videos for technical, professional staff using Lidar as part of a previous Legislative-Citizen Commission on Minnesota Resources (LCCMR) funded project in the early 2010s.

Minnesota USDA-NRCS Engineering Tools/MN DNR Hydrology Tools:

Local, state, and federal field operations staff, as well as private sector engineering firms, use engineering and hydrology tools developed by the USDA-NRCS on a daily basis. Staff view, prepare, and analyze raster-based datasets like Lidar using geographic information system (GIS) and computer aided design (CAD) software.

This tool helps quickly and efficiently delineate watersheds, develop site specific contour maps, and determine the hydrologic impacts for on the ground practices. This tool is used in the various phases of implementing practices such as water and sediment control basins, grassed waterways, grade control structures, and wetland restorations. In addition, the MN DNR has also created a set of complementary GIS tools that are used by professional staff to conduct Lidar analysis and are widely used across the state. These two GIS tools are staples for professional staff utilizing Lidar in their planning and design efforts.

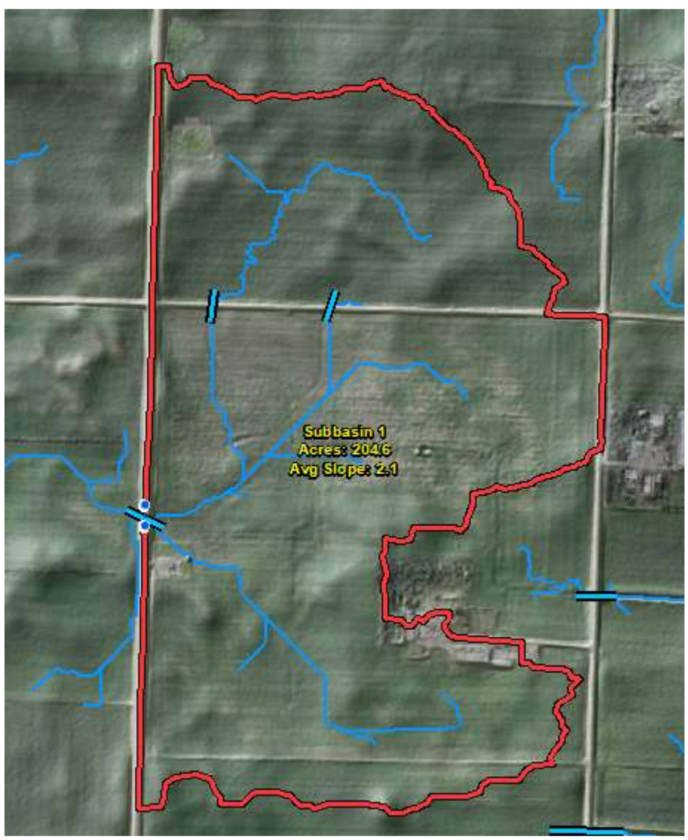

Figure 11: Small watershed delineated on an hDEM using USDA-NRCS Engineering GIS tools.

Identifying Water Storage Areas

The Legislature has appropriated funds to start a water storage program in the Minnesota River Basin and the Lower Mississippi River Basin. (2021 1st Special Session, Chapter 6, Article 1, Sections 4(l), 80.)

Lidar will be instrumental in deciding where storage will be placed by identifying areas with storage potential. BWSR has sought two grants (LCCMR and the NRCS's Conservation Innovation Grant) where Lidar data would help find the best places to store runoff.

Stormwater Management, Surface Water Modeling, and Flood Modeling

Using Lidar with 1-meter and 3-meter digital elevation models (DEMs) allows for accurate mapping of stormwater infrastructure like roadways, curbs, gutters, catch basins, and building elevations. Without these more accurate DEMs, cities would have to use 30-meter DEMs downscaled to 10 meters, but even then this scale would be too coarse to determine where water is going to go.

The Metropolitan Council used the 3-meter DEM extensively for localized flooding work (i.e. bluespot analysis). It was the only dataset used, and the project would not have possible without the Lidar-derived DEM data.

County Geologic Atlases

Geological mapping is primarily conducted to support groundwater protection and management in Minnesota. In addition, geological mapping supports engineering, landslide and sinkhole risk, as well as existing and potential mining, especially for the sand and gravel as well as crushed stone that is needed for construction of roads and building in every county.

The raw Lidar point cloud is the parent example from which many basemaps and layers are derived by the Minnesota Geological Survey (MGS):

- Bare Earth Points
- First return points (the highest features in the landscape, typically treetops, tops of buildings, etc.)

For bedrock mapping, MGS uses the following derived mapping layers:

- Outcrop database (in counties where there is known outcrop)
- Bedrock structure database (in counties where there is known outcrop)
- Lidar (in counties where there is or might be outcrop)
- Air photos (in counties where there is or might be outcrop)
- CWI First Bedrock layers (both vertical and angle holes)
- MN DNR drillhole layer (shows locations of drill core in Hibbing
- Geochron layer (if applicable to the county)
- MGS hand sample layer and thin section associated table (if there are known hand samples/thin sections)
- MGS aeromagnetic and gravity imagery (especially in counties with no outcrop)
- MGS Measured Gravity Points layer (to show the control on gravity and help determine reliability of a signal in any given location)
- MGS Cuttings layer (if bedrock cuttings exist in the county)

For bedrock topography mapping, MGS uses the following:

- CWI bedrock elevation layers (both vertical and angle holes)

- Located wells (with the bottom elevation of each hole labeled to enable me to contour topography)
- Passive seismic database
- Active seismic database
- QDI (used to check for rare bedrock intersections)
- Statewide bedrock topography layer (used for regional context)

MN Agricultural Water Quality Certification Program (MAWQCP)

The MAWQCP uses Lidar on field assessments in two primary ways. First, two-foot contours allow the Minnesota Department of Agriculture (MDA) to determine drainage areas that may need conservation practices. Lidar is also used to develop the hillshade layer the MDA has in its GIS system, which allows the certifier to see where there might be concentrated flow and resulting ephemeral or classic gullies. MDA also can determine if there is overland flow from these tools to determine if filter strips/buffers are needed along streams and ditches or where they might need grade stabilization structures. Lidar also is the source of the digital elevation model (DEM) that MDA uses to determine average slope in fields for determining water quality risk on its assessment tool.

Monitoring and Assessment

The monitoring and assessment work (mostly completed by MPCA and DNR), uses the available LIDAR data frequently. The data is used for:

- Accurately delineating watersheds and contribution areas from the field scale up to the watershed scale.
- Identifying contributing watersheds and area of interest for fish kill investigations and elevated pesticide detection assessments. Lidar helps provide a quicker, more targeted approach for investigation and response.
- Calculating the Stream Power Index (SPI) to identify critical source runoff areas in study watersheds.
- Identifying conservation needs and targeting implementation in agricultural watersheds.
- Dye tracing efforts in the Root River and other watersheds in southeast Minnesota. Dye tracing work is important throughout the entire driftless and karst zone of the region to identify sinkholes and springs.
- Calculating aggregation/degradation of sediment in select areas.

MPCA Watershed Program

The MPCA Watershed Program uses Lidar for the following uses.

Stressor Identification (SID)

- Identifying connectivity issues (barriers to fish and bug movement) that do not show up on aerial photos (small farm road culverts, driveways, small waterfalls)
- Determining how stream gradients influence high and low levels of total suspended solids (erosion and deposition in stream) and low dissolved oxygen concentrations
- Performing desktop reconnaissance of groundwater spring presence or influence in streams
- Finding historical channels in ditched systems (or unmapped channels)

Modeling

- Providing the most accurate digital elevation data for running all HSPF models

Watershed Restoration and Protection Strategies (WRAPS) report development

- Aiding strategy development by assessing hydrogeomorphic risk (slope impacting erosion)
- Aiding in determining surface and groundwater interaction and potential effect to each
- Using structural BMP inventory analyses

Total Maximum Daily Load (TMDL) development

- Used to determine exact watershed boundaries
- Used in source assessment mainly related to sediment

Other Uses

- Altered Watercourse Project/Classification
- Stream Gradient Calculations for defining Stream Class for Index of Biological Integrity
- Determining Stream Flow Direction
- Improving Stream Water Unit ID Geometry
- 3D Imaging and Rendering (i.e. creating geologic models of the lithology in SE Minnesota)

Future Work for Consideration:

Structural BMP Mapping:

Lidar could be used to calculate the total number of BMPs on the landscape, especially in agricultural areas. Currently, BWSR collects geospatial locations of structural and land management practices funded through state dollars through its eLINK Grants Reporting system. Since 2004, about 40,000 best management practices (BMPs) have been entered into the system, but BWSR knows that the eLINK database only contains a fraction of agricultural BMPs. The State of Iowa maps structural BMPs using Lidar through the Iowa BMP Mapping Project. In Minnesota, this data is limited to a few pilot projects that have been completed in small watersheds. This work has been cited as a need in the Minnesota Nutrient Reduction Strategy 5-year Progress Report.

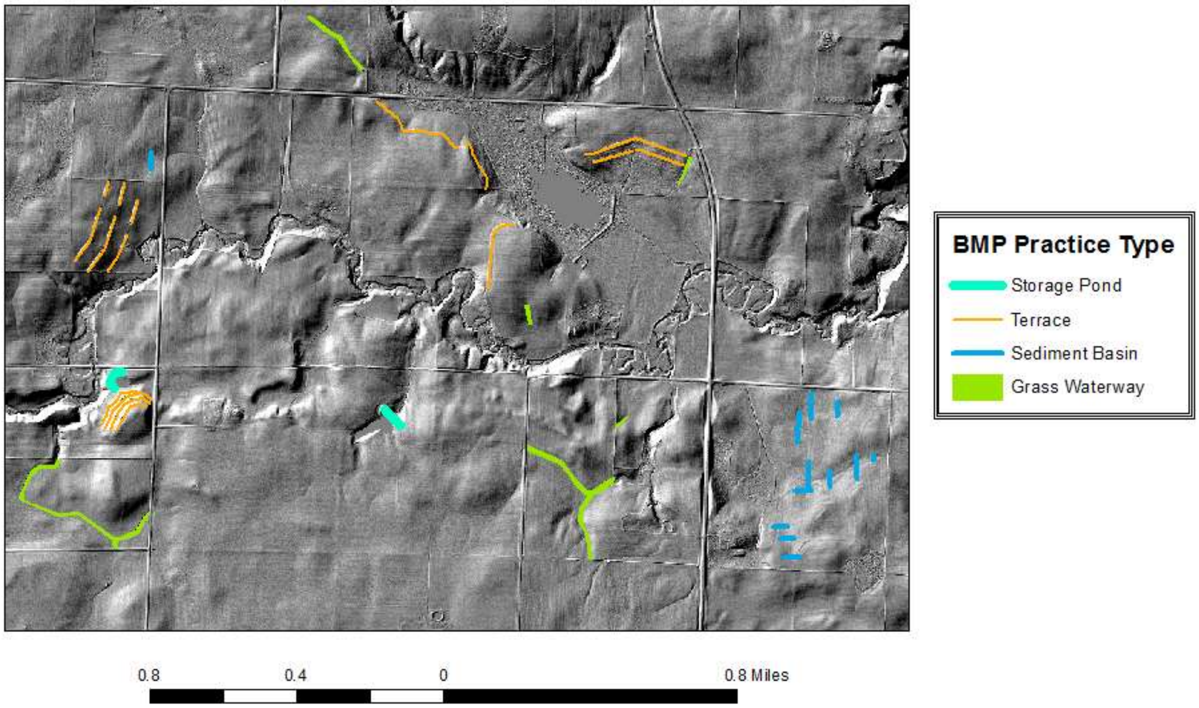

Figure 12: Example of a DEM with a hillshaded backdrop.

Resources:

MnGeo has created several Lidar related products and educational materials for Lidar, which are listed below.

- Reports on previous appropriations: MN Elevation Mapping Project (state.mn.us)
- MnGeo Lidar Resources: https://www.mngeo.state.mn.us/chouse/elevation/Lidar.html
- Minnesota Lidar Plan: https://www.mngeo.state.mn.us/committee/3dgeo/acquisition/Minnesota_State_Lidar_Plan.pdf
- Minnesota Lidar Plan Story Map: https://storymaps.arcgis.com/stories/980394f96f894980a35c6758653bb5ab
- University of Minnesota Lidar Training Materials: https://www.wrc.umn.edu/Lidar-materials
- BWSR Snapshots and Stories
    - Daily Erosion Project: https://bwsr.state.mn.us/sites/default/files/2020-03/Snapshots-story-4-April-2020-Daily-erosion.pdf
    - PTMApp: https://bwsr.state.mn.us/sites/default/files/2020-01/Snapshots-story-4-February-2020-PTMapp%20AW%20edit.pdf
    - Wetland Restoration Site Assessments: https://bwsr.state.mn.us/sites/default/files/2020-05/Snapshots-story-3-May-2020-Survey-then-now.pdf
    - GIS Training: https://bwsr.state.mn.us/sites/default/files/2018-12/Snapshots-story-4-May-2018-GIS-FINAL.pdf

  - Wetland Inventories: https://bwsr.state.mn.us/sites/default/files/2019-01/August%202015%20Snapshot%20%233%20NWI.pdf
- Using Lidar Data to Protect Water Quality (state.mn.us)
- Agriculture and the Environment | Water Resources Center (umn.edu)