Montana Lidar Plan

A Plan for Statewide Lidar Acquisition, Storage, and Distribution

June 2019

Produced by the Montana State Library in Coordination with the Montana Department of Natural Resources and Conservation

Prepared Pursuant to the Montana Land Information Plan, developed in accordance with Section 90-1-404 (c), Montana Code Annotated.

Prepared for and reviewed by the Montana Elevation Working Group for consideration by the Montana Land Information Advisory Council on June 13, 2019

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Prepared for and reviewed by the Montana Elevation Working Group for consideration by the Montana Land Information Advisory Council on June 13, 2019.

Version 0.2, June 2019

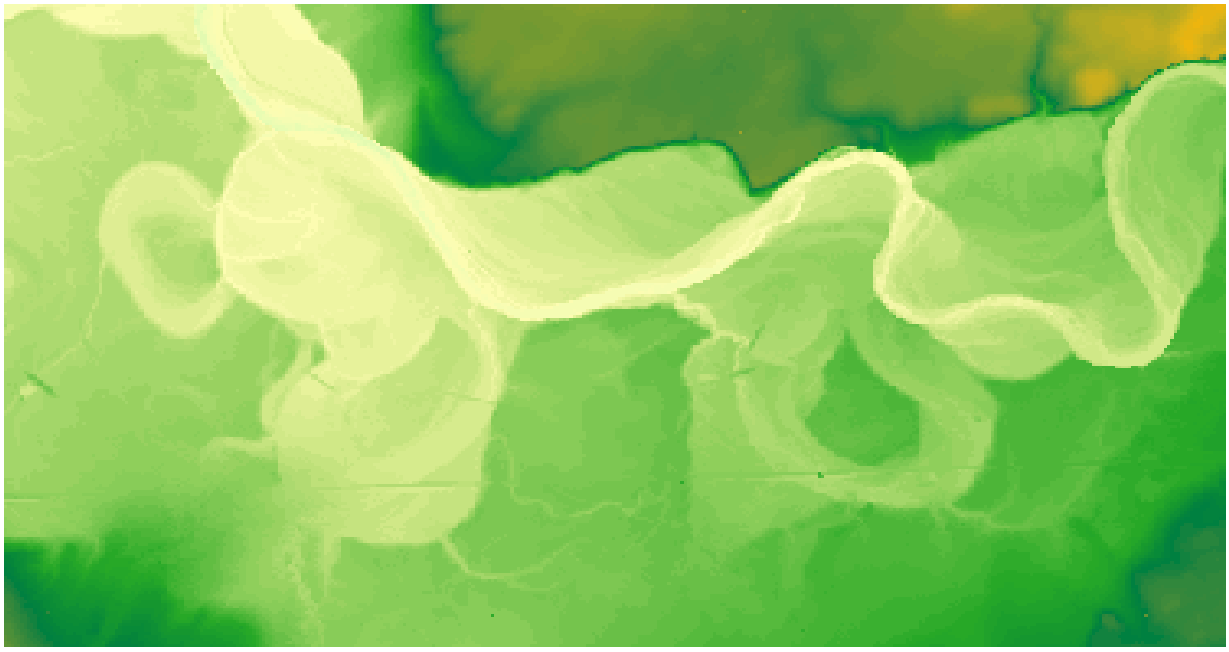
Acknowledgement

In 2018, the National States Geographic Information Council (NSGIC) initiated a project funded by the United States Geological Survey (USGS) to develop a guide for state lidar planning. Montana and seven other states were selected as pilots to participate in the project. The Montana Lidar Plan is the result of that endeavor. Thank you to NSGIC and USGS for being the catalysts for this plan.

Thank you to everyone who reviewed the Montana Lidar Plan.

Comments and suggestions were made by:

- Montana Bureau of Mines and Geology, Mike Stickney and Jeremy Crowley
- Montana Department of Natural Resources and Conservation, Katie Shank
- The Sanborn Company, Inc., Jason Caldwell and Jared Martin
- USDA – Natural Resources Conservation Service, Catherine Maynard, Joshua Robino, and Collin McCormick
- USDA – Forest Service, Robert Ahl
- Montana State Library, Maya Daurio, Michael Fashoway, Erin Fashoway, Evan Hammer, and Jessica Edwards
- Atlantic, Chris Chalmers
- Quantum Spatial, Inc., Melissa Christie and Joel Burroughs
- Montana Natural Heritage Program, Jessica Mitchell



A bare-earth digital elevation model (DEM) of Rock Creek in Valley County showing meanders and old oxbows. Image courtesy of Montana State Library.

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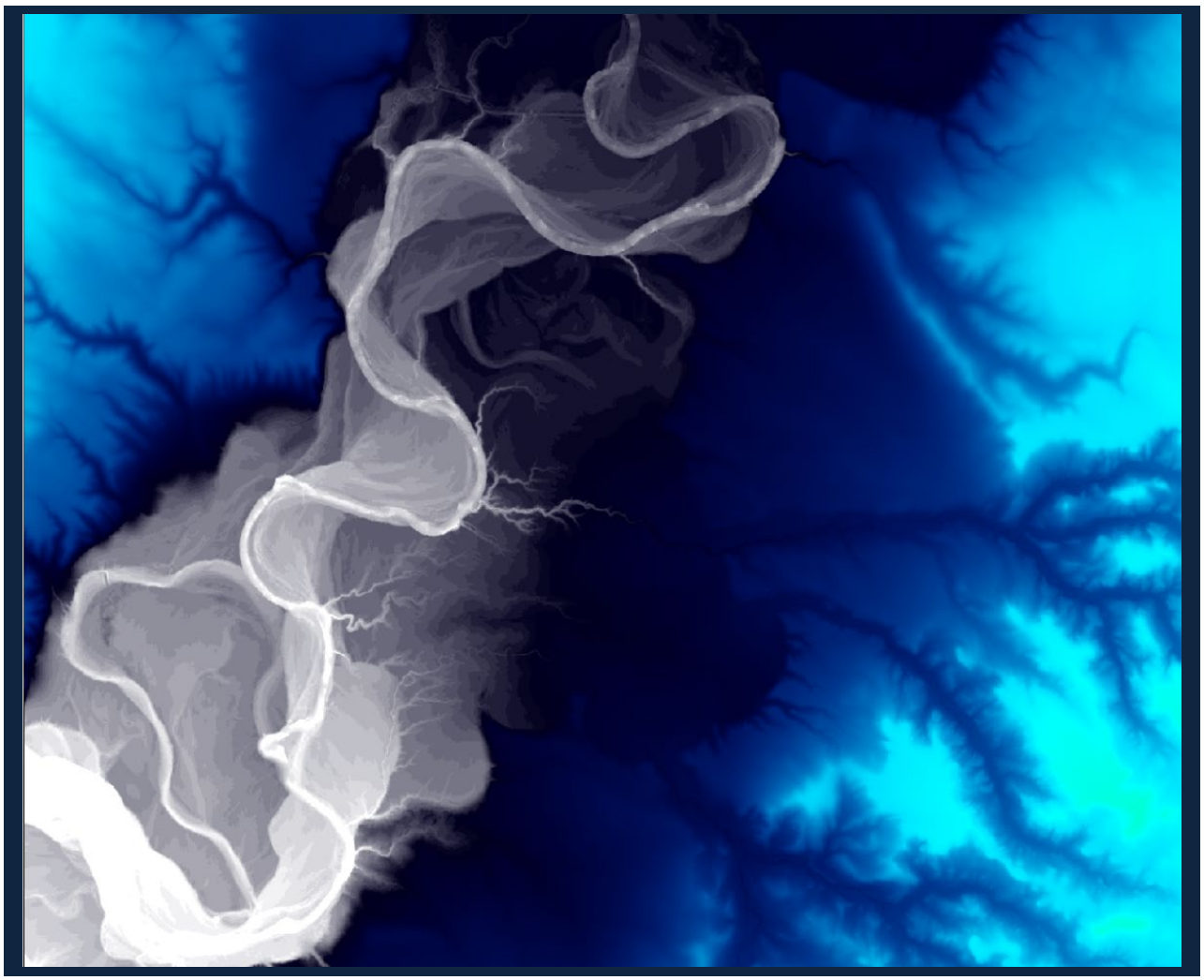


A bare-earth digital elevation model (DEM) of Rock Creek in Valley County showing meanders, oxbows, and tributaries. Image courtesy of Montana State Library.

Executive Summary

In April 2018, the Montana Land Information Advisory Council (MLIAC) approved the Montana State Library as the Montana Spatial Data Infrastructure (MSDI) Elevation Theme Steward. The Montana Land Information Plan State Fiscal Year 2019 identifies development of a statewide lidar plan as a priority for elevation theme development.

The purpose of the Montana Lidar Plan is to provide recommendations for the collection, maintenance, and dissemination of lidar data in Montana. Importantly, the plan creates an avenue for state, local, and tribal entities to acquire lidar data through partnerships and coordination with the Montana Elevation Working Group (MEWG) and the Montana State Library. The desired outcome of this plan is statewide lidar coverage by the end of 2023. This is in line with the U.S. Geological Survey's goal of nationwide lidar coverage.

To date, most lidar acquisitions in Montana have been focused on individual projects rather than targeting a larger goal of statewide lidar coverage. In order to get the best return on this large investment, lidar should be collected in a systematic way and strive for partnerships, cost-sharing, maximizing potential use, and collection over large expanses. Countywide collection is recommended as the preferred geographic unit for future acquisition planning.

The Montana Lidar Plan makes ten recommendations:

1. Enhance the Montana Lidar Inventory to readily report overlapping areas of interest, with the purpose of prioritizing areas by county based on partnership opportunities. Actively engage additional Montana experts from various professions and sectors to submit their priority areas of interest. Include federal priorities from SeaSketch in the Montana reporting. The Montana Lidar Inventory is available at: http://msl.mt.gov/gis/lidarinventory.

2. Develop tools to simplify the collection of lidar data in Montana, including a USGS 3D Elevation Program Broad Area Announcement (3DEP BAA) application template that cites the Montana Lidar Plan and a template contract/MOU for potential future 3DEP BAA partners to contribute funds to MSL. These templates will expedite application development and demonstrate that Montana is coordinated and has a plan.

3. Task the Montana Elevation Working Group with actively pursuing partnership opportunities when new collections are in the early planning phase or where there are overlapping priority areas of interest.

4. Task the Montana Elevation Working Group with providing technical assistance and review of 3DEP BAA applications and other lidar task orders in Montana.

5. The Montana State Library should seek funding needed to meet the tremendous data processing and storage needs of a lidar repository. The needs cannot be assumed without funding.

6. Develop a Montana lidar repository at the Montana State Library that will become the primary source for lidar data and derived products in the state. Expand the Montana Lidar Inventory to become a lidar viewer and download platform.

7. Based on the priorities identified in this plan, develop and submit a countywide or larger 3DEP BAA application by October 2019. Continue to submit 3DEP BAA applications that support the Montana Lidar Plan in subsequent years.

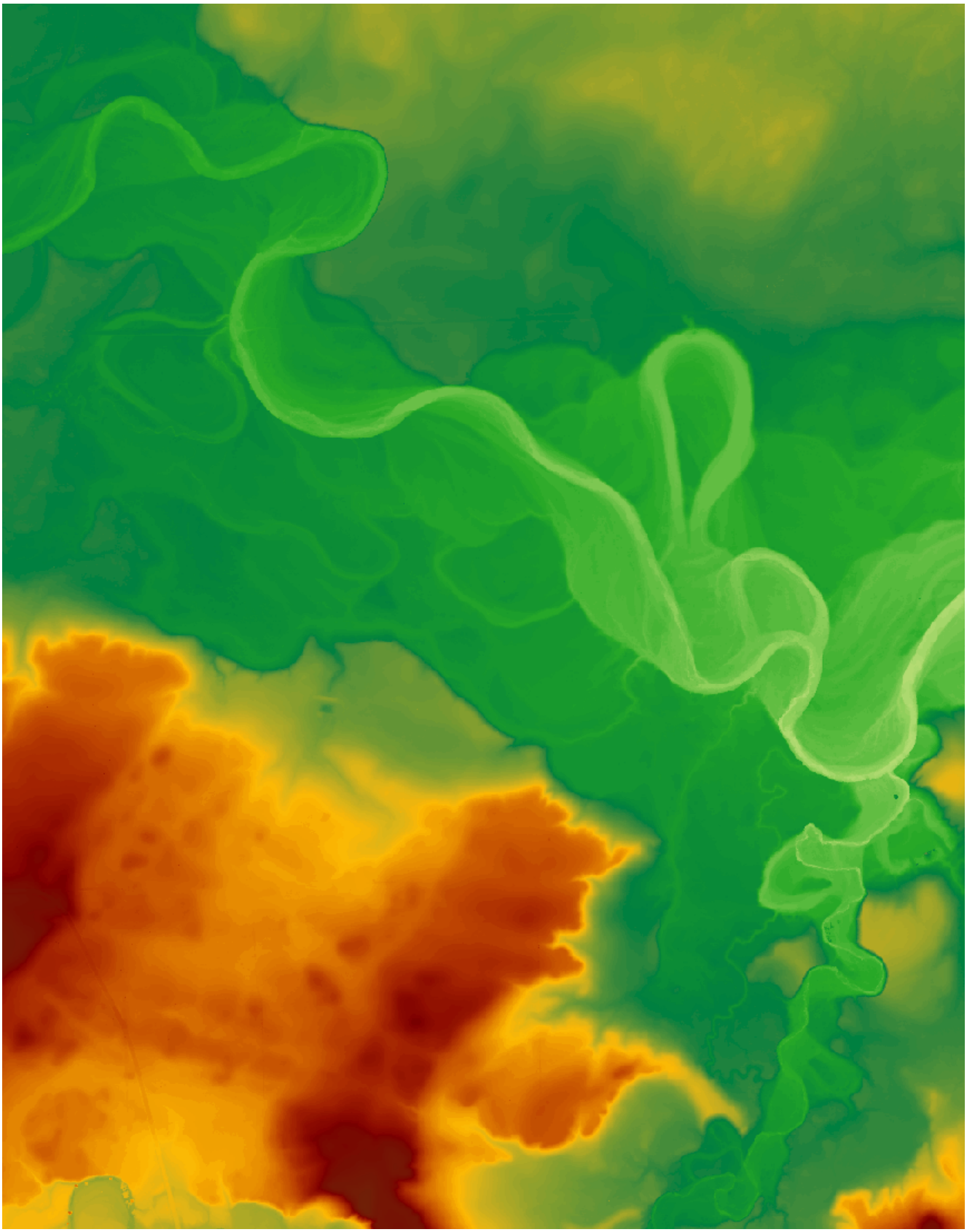
   The Montana State Library should develop lidar acquisition partnerships with interested stakeholders that are formalized through cooperative agreements and/or MOUs. The intent of this recommendation is to allow for the pooling of stakeholder resources to achieve the common goal of statewide lidar data collection.

8. Develop Montana Lidar Plan outreach materials, such as posters, postcards, one-pagers, and presentations.

9. Identify and engage constituents with an interest in championing legislation to make a seed capital investment in lidar.

Plan Execution Status Table:

Recommendation	Approximate Schedule	Status (Aug. 2019)
1. Enhance Lidar Inventory web application. Increase expert input on AOIs.	Summer 2019	Early developments
2. Tools to simplify the collection of lidar data, such as a template BAA application and MOUs for pooling resouces	October 2019	In progress (template BAA ready May 2019)
3. Actively engage and pursue partners	Ongoing cycle	Started (ramp up needed)
4. Technical assistance with lidar specifications/deliverables	Ongoing	Ready
5. Seek funding for storage/processing	--	Not started
6. Develop lidar repository	Draft release summer 2019	Early developments
7. Submit countywide 3DEP BAA	October 2019, then annually	Completed May 2019 Next due Nov. 2019
8. Outreach – posters, postcards, one-pagers, and presentations	Ongoing	Started (ramp up needed)
9. Champion	--	Not started



A bare-earth digital elevation model (DEM) of Rock Creek in Valley County and its tributary Bluff Creek. Image courtesy of Montana State Library.

Introduction

The Montana Land Information Act (MLIA) requires that an annual land information plan be prepared that describes Montana's priority needs in regard to the collection, maintenance, and dissemination of land information (MCA 90-1-404(c)). The Montana Land Information Plan 2019/2020 identifies development of a statewide lidar plan as a priority, and, in April 2018, the Montana Land Information Advisory Council (MLIAC) approved the Montana State Library as the MSDI Elevation Theme Steward.

Shortly thereafter, the Montana Elevation Working Group (MEWG) was formed. Made up of experts from state, federal, local, tribal, and private organizations who use elevation data, the working group's purpose is to provide technical recommendations and guidance in the collection, maintenance, and distribution of elevation data. In agreement with the Montana Land Information Plan, the first task taken on by the newly formed MEWG was the development of a Montana Lidar Plan that would set the path for attaining statewide high-resolution elevation coverage.

Image courtesy of Quantum Spatial, Inc.

The preferred technology for collecting high-resolution (i.e., 1 meter or better) elevation data over large expanses is airborne Light Detection and Ranging (lidar). Lidar is a remote sensing technique that uses light in the near-infrared or green wavelength to measure distances. A laser ranging device mounted on an aircraft emits hundreds of thousands, even millions, of pulses of light towards the earth's surface. Some of the energy is reflected back to the lidar sensor, which uses the speed of light to determine how far the light traveled. Airborne lidar is used to generate high-quality 3D information about the bare earth (beneath vegetation), its elevation, and the height of surface characteristics, such as vegetation, buildings, and other structures.

The Montana Lidar Plan provides a strategy for completing statewide lidar coverage in Montana. The plan provides an overview of lidar benefits and uses, a list of stakeholders and roles, past collection efforts, the status of lidar holdings, and recommended specification standards for collecting point cloud data and deriving rasterized products. Most importantly, the plan creates an avenue for state, local, and tribal entities to acquire lidar data through partnerships and coordination with the MEWG and the Montana State Library. The guiding principle of the Montana Lidar Plan is to be inclusive and maximize the number of uses and potential benefits of lidar acquisitions.

Purpose

The purpose of the Montana Lidar Plan is to provide recommendations for the collection, maintenance, and dissemination of lidar data in Montana. The goal of the plan is statewide lidar coverage by the end of 2023. States with a plan are in the best position to leverage funding opportunities and achieve statewide lidar coverage.

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Problem Statement

Most lidar acquisitions in Montana have been single-agency with few partnerships, collected over relatively small expanses, and, oftentimes, project specific. This piecemeal approach is not cost-effective, is hard to manage, is expensive to fly, does not realize the full potential of lidar uses, and can lead to overlapping acquisitions. Duplication of efforts should be minimized due to the cost of lidar, especially when the initial goal is to complete uniform statewide coverage. Future lidar acquisitions in Montana should be done in a systematic way and strive for partnerships, cost-sharing, maximizing potential use, and collection over large expanses.

Most states in the Midwest, South, and Northeast have complete, or nearly complete, statewide lidar coverage, if quality level and collection date are disregarded (**Figure 1**). Additionally, multiple states (e.g., Ohio, Pennsylvania, Indiana, North Carolina, Kansas, Alabama, and others) are in the process of reacquiring statewide lidar, largely by leveraging the United States Geological Survey (USGS) 3D Elevation Program (3DEP). Meanwhile, lidar coverage is woefully incomplete in the West. Approximately 70% of Montana lacks any lidar coverage, and an additional 5% of the state lacks lidar coverage satisfying USGS baseline specifications (**Table 1**).

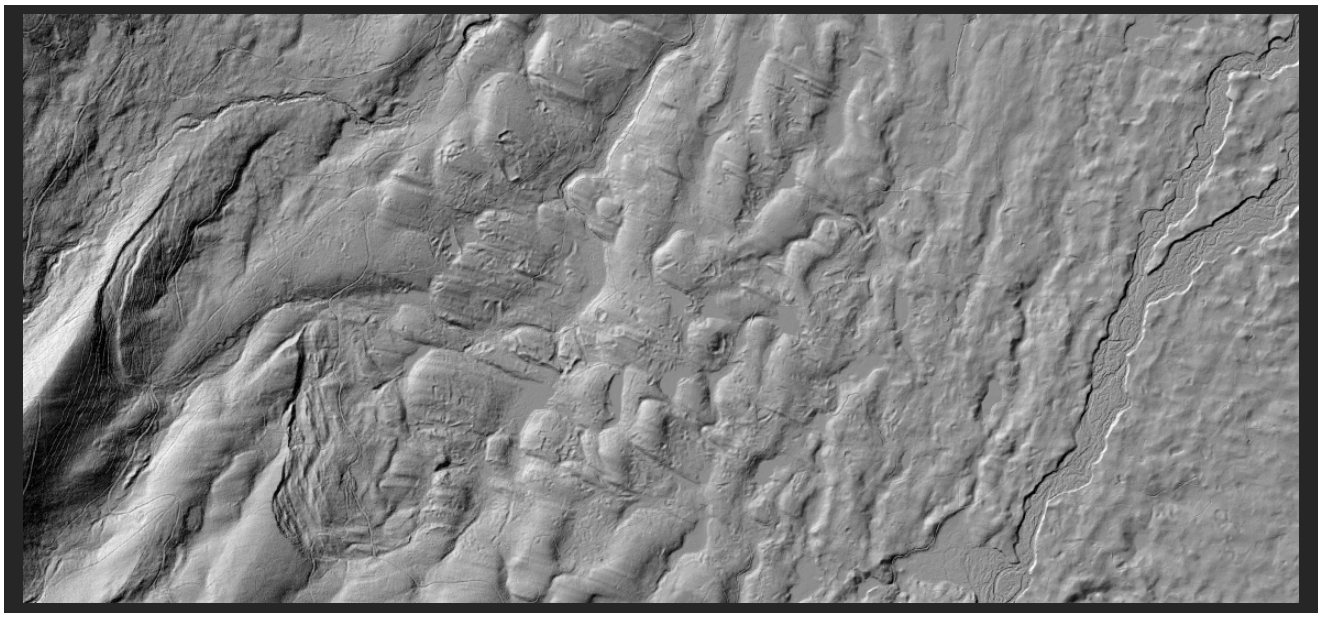


Image of bare-earth elevation. Image courtesy of Robert Ahl, US Forest Service.

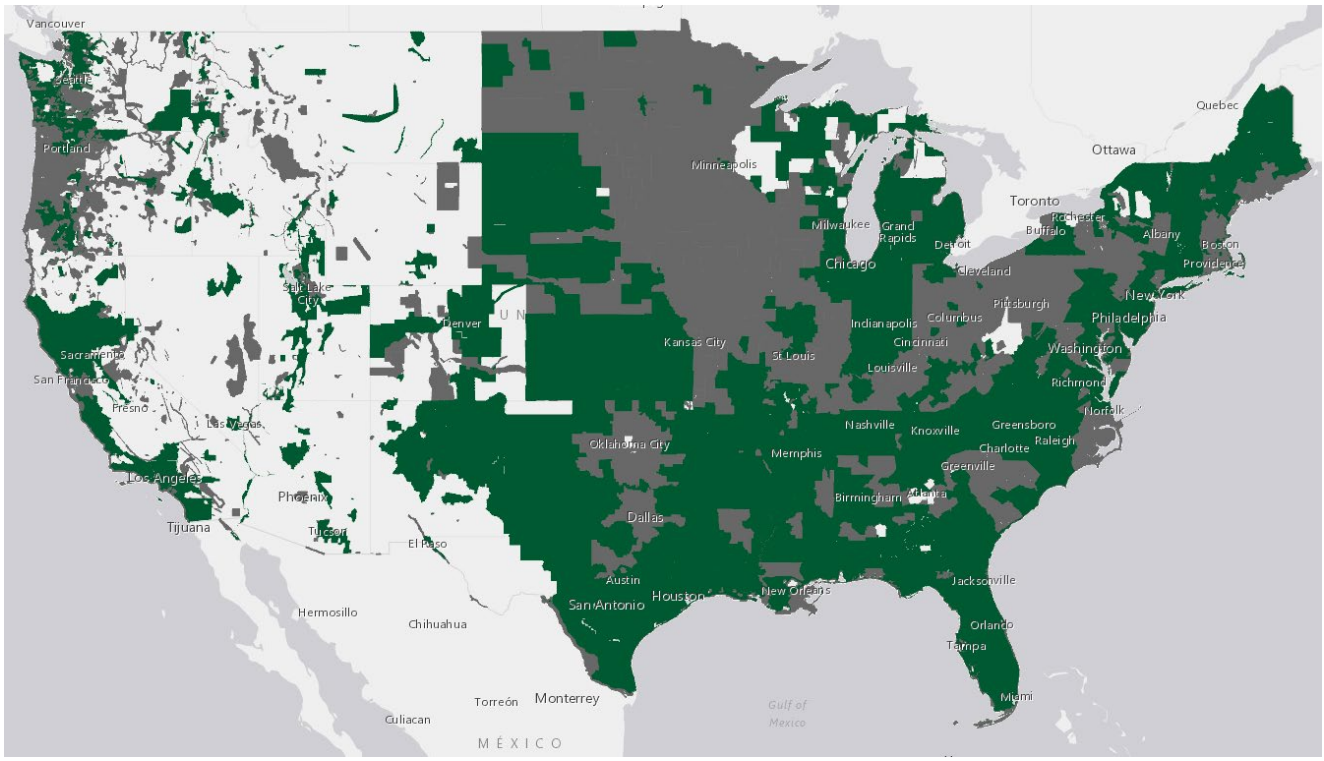


Figure 1. *Map of lidar coverage for the contiguous United States, March 2019. Gray represents publicly available lidar of any quality level and collection date; green represents lidar satisfying USGS 3DEP baseline specifications. 3DEP-quality lidar data is available for approximately 53% of the nation. Montana lidar coverage of any quality is approximately 30%. (Figure from online web application, Seasketch: U.S. Federal Mapping Coordination).*

Description	Square Miles	Percent of MT Total Area
Existing lidar coverage, any quality and any collection date	47,000	32%
Existing lidar coverage meeting USGS baseline specifications (QL2 or better)	42,000	28%
Existing lidar coverage that has become dated (more than 10 years old, 2008)	500	< 1%
Overlapping acquisitions	2,000	< 1%
Lidar needed to reach the goal of the Montana Lidar Plan (complete coverage)	100,000	68%

Table 1. *Montana lidar coverage by the numbers, as of May 2019. The total area of Montana is 147,000 square miles.*

The USGS developed the 3D Elevation Program (3DEP) to systematically acquire high-resolution elevation data for the nation by the end of 2023. The program provides cost-sharing towards lidar acquisitions, contracting support, quality assurance, and information-technology expertise. Prior to 2019, Montana has not leveraged this program, though there was an application submitted and approved in the first year of the program. This award was abandoned, however, due to lack of sufficient matching funding. Montana should organize and plan to leverage the 3D Elevation Program whenever possible.

Benefits of High-Resolution Elevation Data

High-resolution elevation data derived from lidar offers tremendous opportunities for many sectors and disciplines across Montana. All levels of government and many other organizations stand to benefit. Currently, the best available statewide elevation coverage is the 10-meter resolution historic National Elevation Dataset (NED). Whereas the accuracy of NED is reported in meters with an absolute vertical accuracy expressed as Root Mean Squared Error of 2.4 meters (Gesch et al., 2014), the accuracy of elevation collected in the form of lidar is presented in centimeters with a vertical accuracy of, for example, 10 cm. The greater accuracy of elevation from lidar meets detailed topographic mapping and analysis needs where NED falls short, such as for transportation modeling, flood-risk management, infrastructure and construction management, precision farming, forest structure and health, and geologic-resource and natural-hazard analysis. Lidar also offers cost-savings compared to traditional field surveys because it can be collected over large expanses, many of which are inaccessible to land-based surveys.

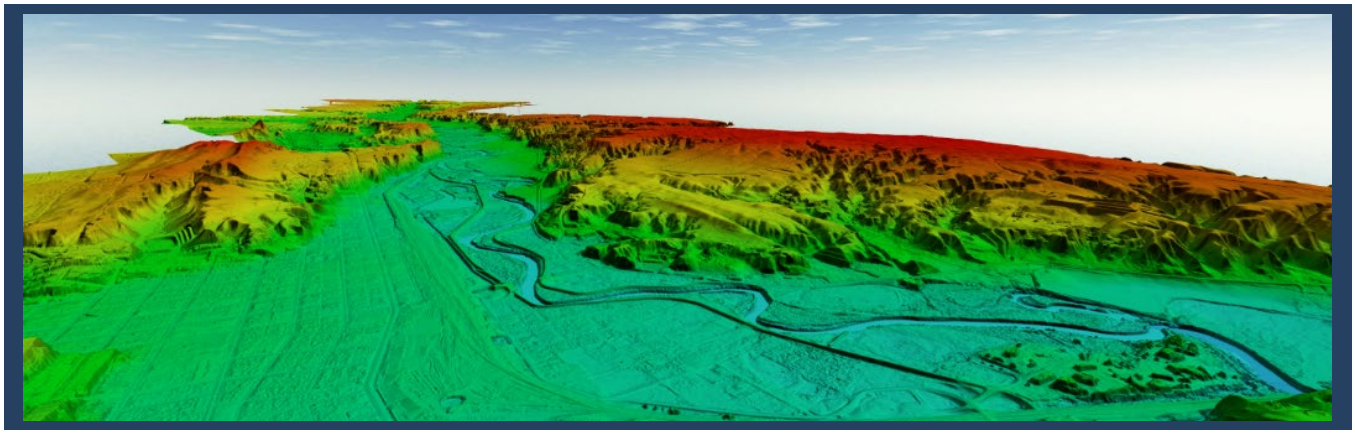
In 2014, the benefit-cost ratio of lidar for Montana was conservatively estimated at 2.1 to 1, with total annual benefits (**Table 2**) conservatively estimated at $13.08 million (Carswell, 2014 and Maune, 2017). Lidar costs over the last five years have decreased, making the return on investment significantly higher today.

Higher quality elevation data leads to a better understanding of the earth and its surface characteristics.

Though expensive, the collection of elevation data in the form of lidar has an excellent benefit-cost ratio and return on investment.

Expected annual benefits	$13.08 million
Payback	3.8 years

Table 2. *The benefits and costs of high-resolution elevation data collected in the form of lidar. Dollar estimates shown are the most recent available (2014). The benefit and payback period estimates are highly conservative. (Table from Carswell, 2014)*



Looking west from downtown Havre, Montana. Image courtesy of Woolpert.

Lidar Uses and Opportunities for Montana

The National Enhanced Elevation Assessment is the most comprehensive study of high-resolution elevation data needs and uses (Maune, 2017). **Table 3** lists the top ten business uses for lidar data in Montana.

Today, the business use with the most benefit being realized is flood-risk management. Through funding from the Federal Emergency Management Agency, the Montana Department of Natural Resources and Conservation has acquired 75% of Montana's lidar coverage, primarily for flood-risk mapping. Other major uses of public-domain lidar are summarized by sector, agency, and primary use in **Appendix A**, which is based on MEWG participation and is not an exhaustive list of Montana lidar use. **Appendix A** is summarized as a graphic in **Figure 2**.

Rank	Business Use	Annual Benefits (million)
1	Natural-resources conservation	$4.86
2	Agriculture and precision farming	$3.48
3	Water supply and quality	$1.18
4	Infrastructure and construction management	$1.09
5	Flood-risk management	$0.83
6	Geologic-resource assessment and hazard mitigation	$0.72
7	Forest resources management	$0.4
8	Wildlife and habitat management	$0.2
9	Renewable-energy resources	$0.14
10	Aviation navigation and safety	$0.1
	Other	$0.08
	Total	**$13.08**

Table 3. *Montana top 10 lidar business uses, as identified in the National Enhanced Elevation Assessment, 2014 (Carswell, 2014).*

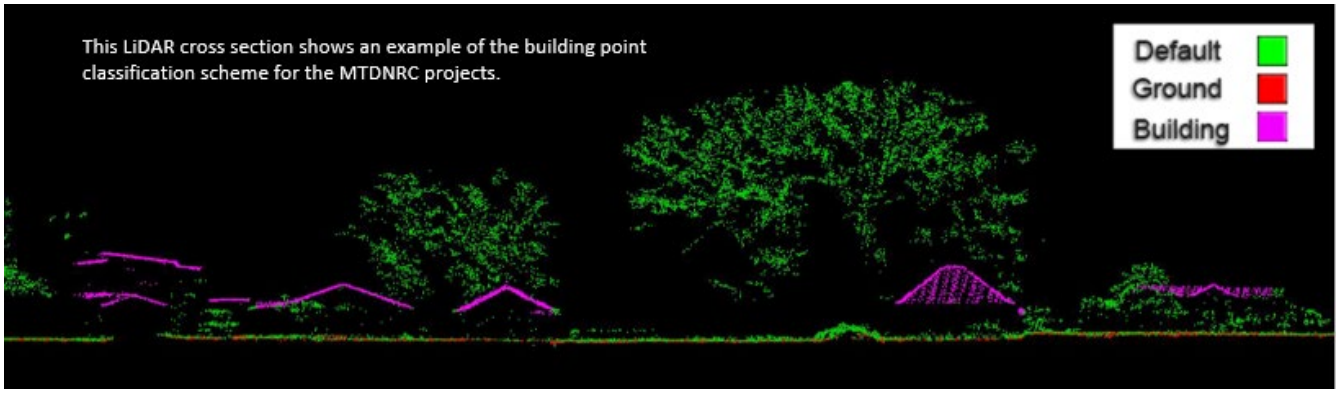


Image courtesy of Quantum Spatial, Inc.

Figure 2. *Montana stakeholder business uses of lidar data. Numbers shown represent Montana Elevation Working Group participants and are not intended as a summary of all Montana business uses of lidar.*

Stakeholders, Roles, and Coordination

Montana stakeholders are organized under the Montana Elevation Working Group (MEWG) and Charter (**Appendix B**). The MEWG is led by the Montana State Library and is open to all who are interested. Membership consists of "Active Participants," who actively engage in state lidar planning and tasks, and "Recipients," who primarily want to be kept informed and receive meeting invites and notes. Active participants and their major role/expertise are listed in **Appendix B**. Resources required for the functioning of the MEWG are the volunteered time of its membership for meetings, research, and the execution of workgroup tasks. The MEWG is the coordination and communication foundation necessary to execute the Montana Lidar Plan.

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The MEWG met approximately monthly from November 2018 to February 2019 to discuss and develop content for the Montana Lidar Plan. Going forward, the MEWG anticipates meeting approximately quarterly depending on need.

Past Acquisitions and the Montana Lidar Inventory

Current lidar holdings across Montana exist as a mixture of projects, collection dates, and quality levels conducted over a period beginning in 2005 and continuing to the present, with the majority of lidar collection (70%) occurring in 2018 and 2019. Past lidar collections have been relatively small, averaging 200 square miles, and have been project-focused (single-agency with few partnerships). Project footprints often follow river and stream corridors, reflecting the primary use for flood-risk management and the primary state agency that acquires lidar, the Montana Department of Natural Resources and Conservation (DNRC).

Most lidar acquisitions to date in Montana have been conducted by a single agency, rather than built on partnerships.

Federal funding has been critical for lidar acquisitions in Montana. The DNRC Water Resources Division is the primary state agency that acquires lidar, but these acquisitions have been funded by the Federal Emergency Management Agency (FEMA). The USDA Natural Resources Conservation Service, US Army Corps of Engineers, USDA Forest Service, and Ravalli County round out the top five agencies that fund and acquire lidar in Montana. **Figure 3** lists the square miles of lidar acquired by various organizations, and **Figure 4** summarizes square miles acquired by year.

Federal funding has been critical for lidar acquisitions in Montana.

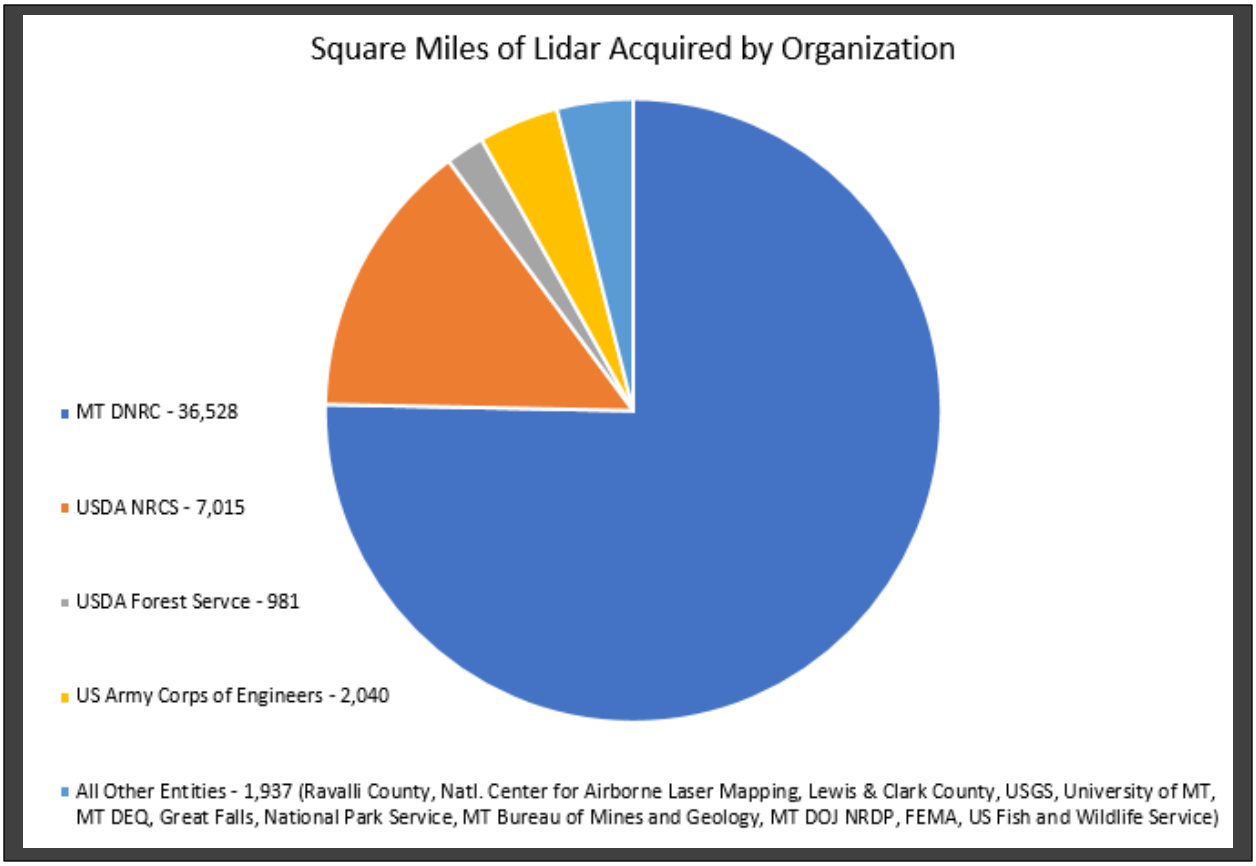


Figure 3. *Square miles of lidar acquired by organization.*

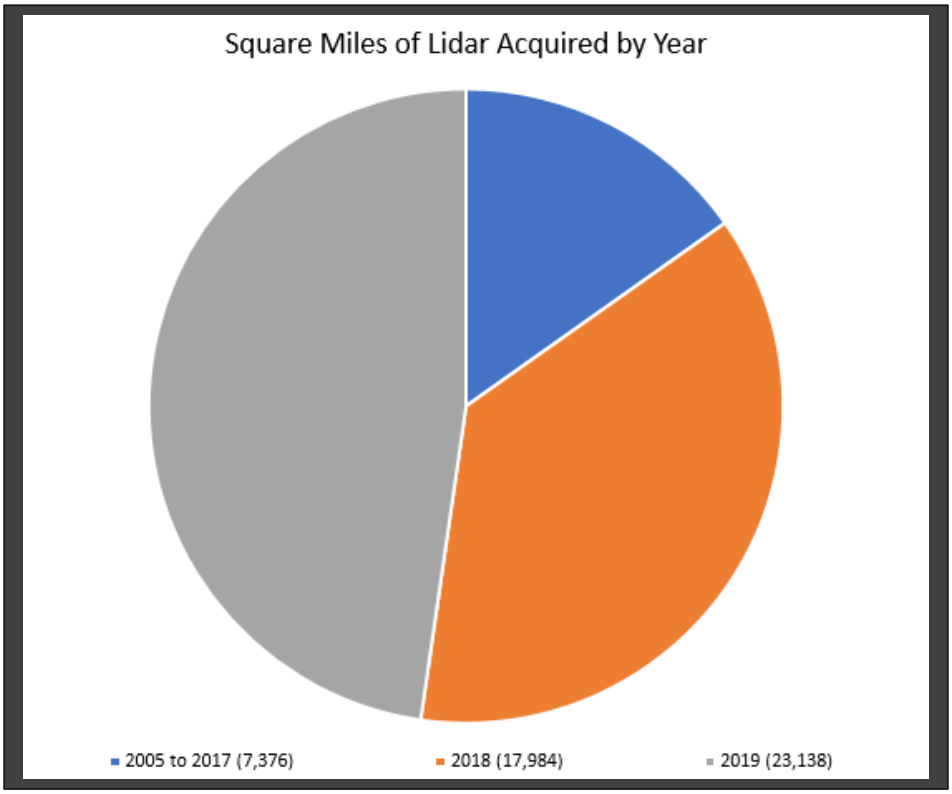


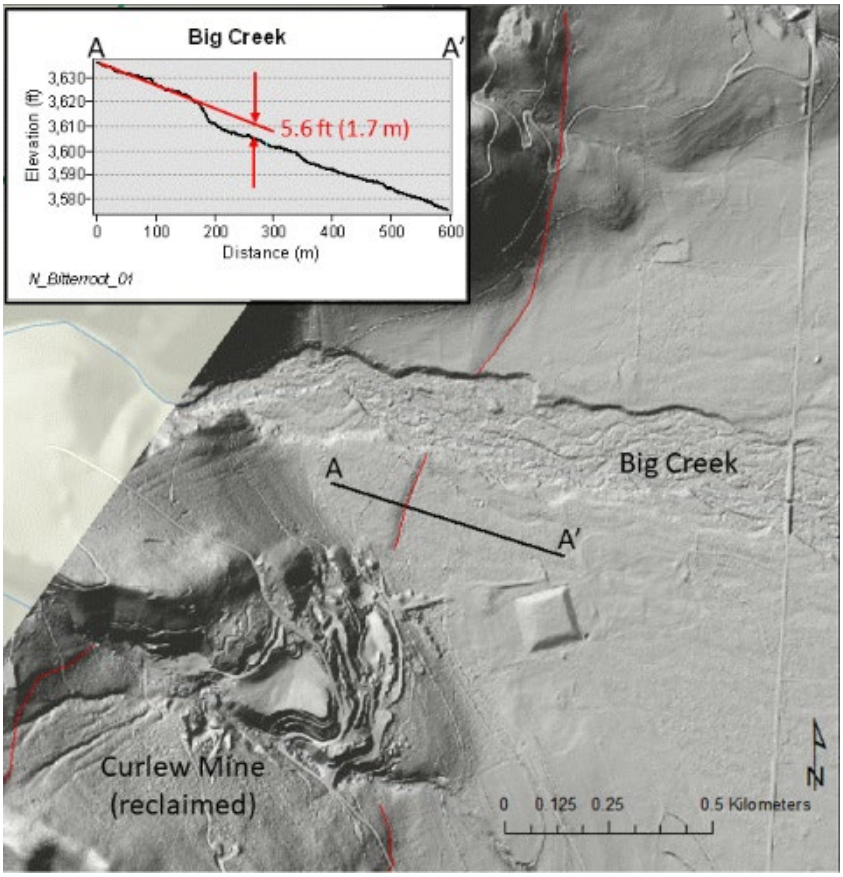
Figure 4. *Square miles of lidar acquired by year.*

The Montana Lidar Inventory (http://msl.mt.gov/gis/lidarinventory) is an online web application that depicts where high-resolution elevation data has been collected. It is a GIS database with accompanying online maps depicting existing and future lidar acquisitions. The inventory depicts project footprints of:

1. Completed/in-progress acquisitions (**Figure 5**);
2. Planned lidar acquisitions; and
3. Priority areas of interest for future acquisitions (**Figure 6**).

Additionally, a companion questionnaire allows anyone to submit completed and upcoming acquisitions that are missing from the inventory. The Montana Lidar Inventory includes attributes and metadata, such as project name, collection date, collection agency, quality level, and links to final delivery reports.

Nationally, the United States Interagency Elevation Inventory (USIEI) (https://coast.noaa.gov/inventory/) is a comprehensive listing of high-accuracy elevation data. The USIEI and the Montana Lidar Inventory complement each other, with the Montana database serving as a reliable local source for updating the nationwide database. The Montana State Library coordinates inventory updates with the USGS National Map Liaison approximately annually.



Bare-earth lidar image showing the Bitterroot Fault scarp offsetting the youngest glacial outwash surface of Big Creek just north of the Curlew Mine. Inset shows topographic profile indicating 1.7 m of tectonic offset across the fault along profile A-A′. (Image courtesy of Montana Bureau of Mines and Geology.)

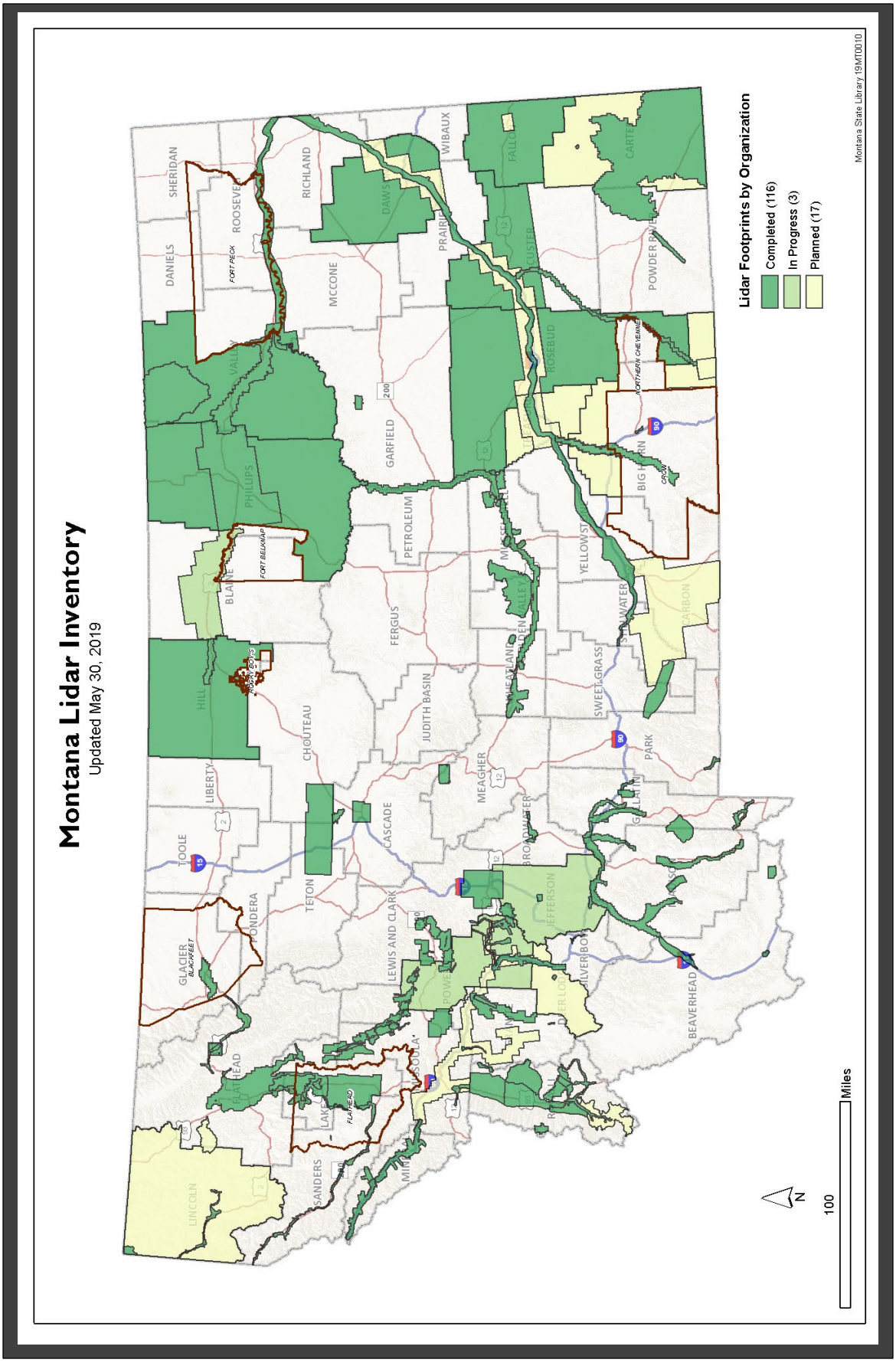


Figure 5. *Map of completed (red) and planned (green) lidar acquisitions. Planned acquisitions are expected to occur in 2019/2020.*

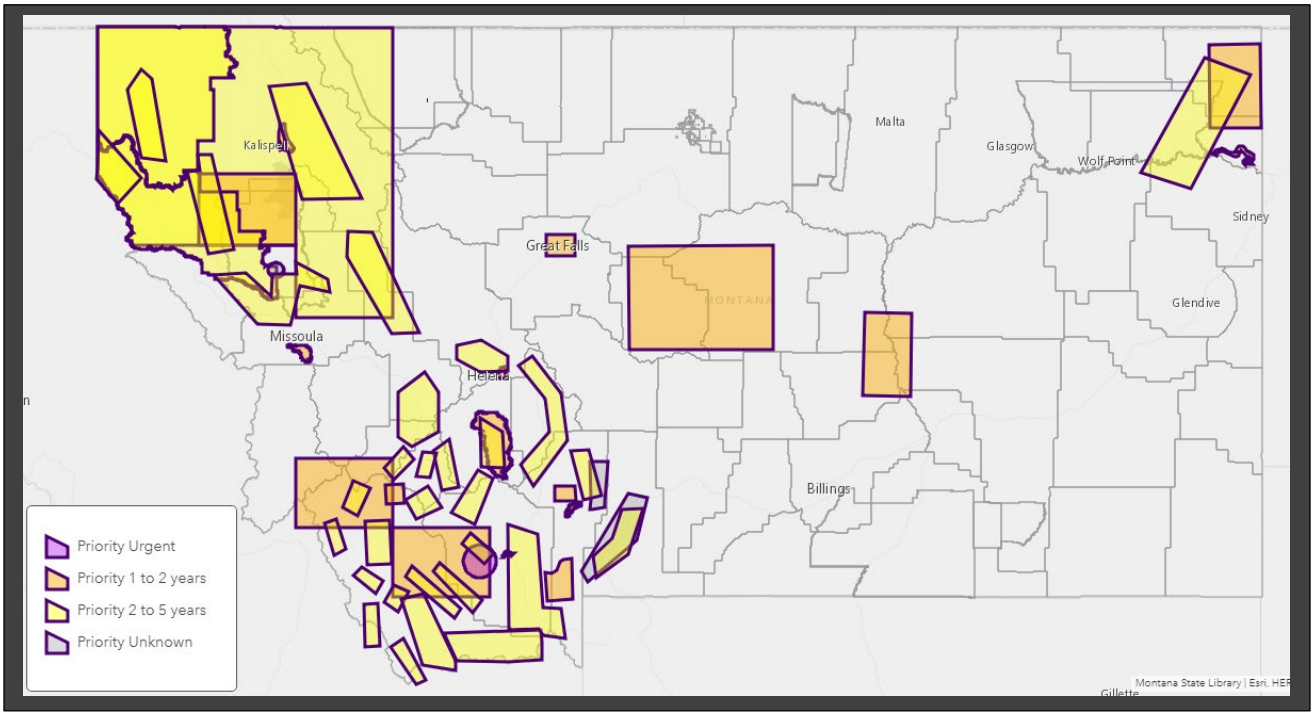


Figure 6. *An example of user-submitted priority areas of interest for future lidar acquisitions. Areas of overlap signify potential partnership opportunities. The map is updated regularly and the most current one is available at: http://www.msl.mt.gov/gis/lidarinventory*

Future Acquisition Prioritization

In 2018, the Montana Department of Natural Resources and Conservation (DNRC) adopted a general strategy of collecting lidar countywide whenever feasible. Collecting lidar over large areas is more cost-effective than collecting a patchwork of smaller, corridor-like areas. Large acquisitions are also more conducive to partnerships. Grant reviewers often highly value a variety of partnerships and potential uses (small contributions from many partners are more impressive than large contributions from only one or two partners). Going forward with the Montana Lidar Plan, lidar acquisition planning should be done countywide or larger.

Statewide acquisition planning requires prioritization of areas to be collected. There are many approaches to prioritizing areas of interest. Some states (e.g., Idaho and Washington) have conducted surveys or stakeholder meetings to evaluate priority ranking of counties, subbasins (HUC-8 digit), or other extents. Montana should take an opportunity-oriented approach that focuses on identifying partnerships and leveraging the USGS 3D Elevation Program to maximize funds. For example, as of March 2019, the "opportunity" is FEMA funding made available to the Montana DNRC for flood-risk management. The DNRC should identify its priority areas of interest, then the MEWG can focus on identifying additional priorities and contacting potential partners in contiguous or nearby areas.

"Opportunity" also exists where there are mutual priority areas of interest, as displayed in the Montana Lidar Inventory (**Figure 6**). Such an approach is similar to a survey or stakeholder meeting approach in that users record (draw) their priority areas of interest. Areas of overlap signify potential

partnership opportunities. This approach to prioritization could potentially overlook high-impact uses of lidar, such as risk to human population or natural hazards, but this could be minimized by making sure a range of experts across various sectors (federal, state, county, local, tribal) are adding their areas of interest.

Federal agencies routinely use SeaSketch to display agencies' priority areas of interest; however, it has been underused by state and local governments, especially in Montana. There are many layers displayed in SeaSketch, and they can be cumbersome to sort through nationwide. The Montana Lidar Inventory simplifies the layers and displays them for Montana only. As a general practice, federal agencies should submit lidar priority areas through SeaSketch, and state, county, local, and tribal organizations should submit priority areas through the Montana Lidar Inventory. Both applications should be consulted when attempting to identify potential partnerships. The Montana State Library MSDI Elevation Theme Lead serves as a Montana point of contact for both applications.

Recommendation 1: Enhance the Montana Lidar Inventory to readily report overlapping areas of interest, with the purpose of prioritizing areas by county based on partnership opportunities. Actively engage additional Montana experts from various professions and sectors to submit their priority areas of interest. Include federal priorities from SeaSketch in the Montana reporting.

A phased, multi-year approach to achieve statewide lidar coverage is proposed in **Figure 7.** Counties are prioritized for acquisition based on:

1. Priority 1 – Regional Consistency – finish partially completed counties and fill in gaps between counties for temporal consistency (planning ~2019 - 2020).

2. Priority 2 – Hazard Mapping – collect counties with geological hazards and high-hazard dams (planning ~2020 – 2021).

3. Priority 3 – State and Federal Priorities – collect counties with large portions of state and federal areas of interest (planning ~2021-2022).

4. Priority 4 – Complete Statewide Coverage – collect counties with few priorities identified to date (planning ~2022-2023).

Figure 7 is intended for planning purposes, and future acquisitions are likely to vary from this plan. County prioritization will be reevaluated regularly by the MEWG.

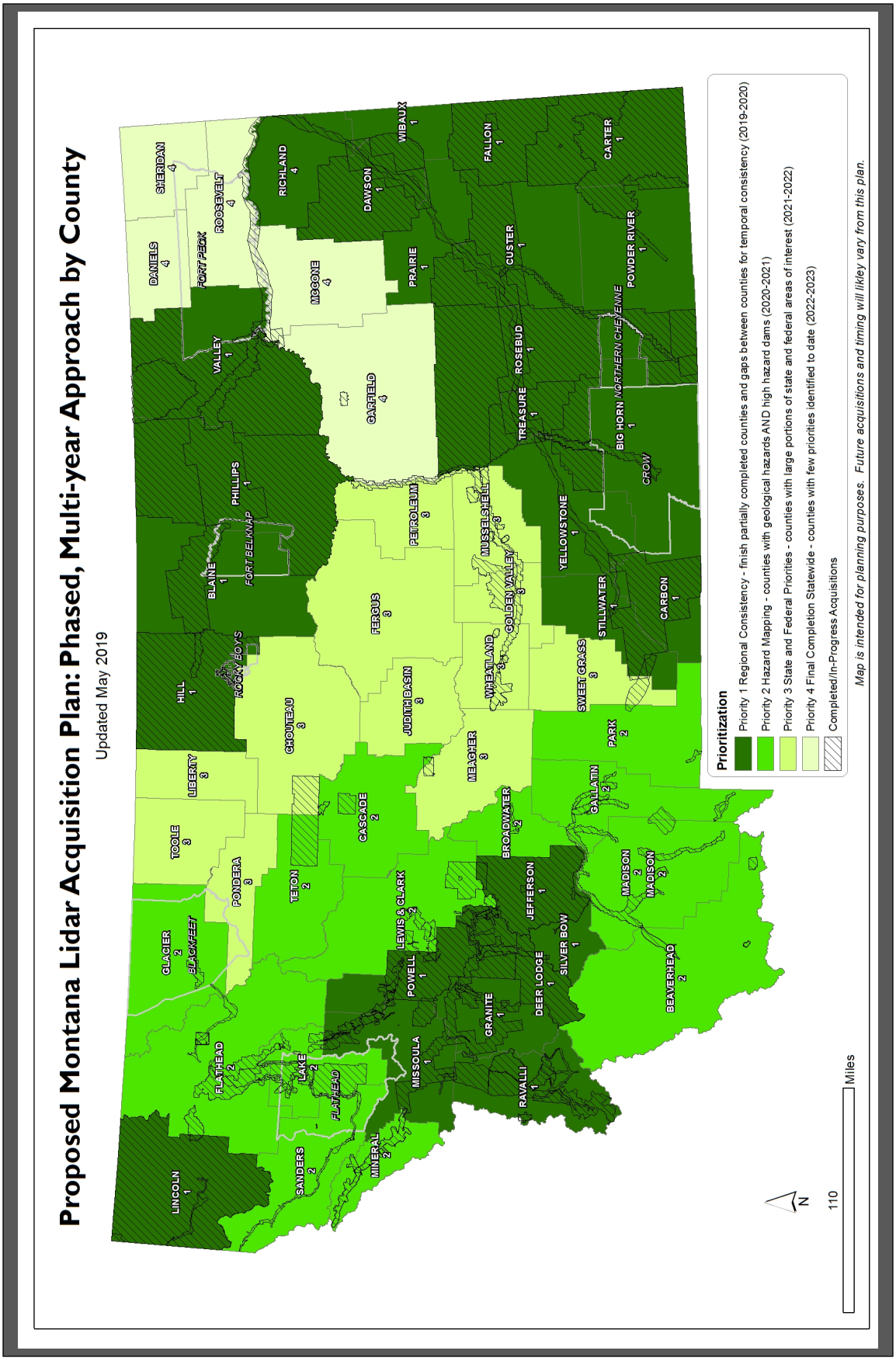


Figure 7. *Map of a phased, multi-year approach to acquire lidar by county.*

Partnerships and Collaborations

Montana averages more than $1.5 million spent annually on lidar. These dollars should be maximized through partnerships (state, county, local, or tribal) that leverage grant opportunities, especially the 3D Elevation Program.

Differing fiscal and project timelines have made lidar acquisitions through multi-agency partnerships difficult. While this timing challenge is expected to continue, having the Montana Lidar Plan in place will assist with aligning partnership efforts. Ideally, acquisition planning should be in motion approximately 18 months ahead of the planned collection date so that multiple funding avenues can be explored (**Table 4**).

Any organization planning to acquire lidar data should first check the Montana Lidar Inventory to see what is already available or planned for acquisition. Next, an email should be sent to the Montana Elevation Working Group announcing that an acquisition is in the early stages of planning. A footprint of the planned collection area should also be provided in shapefile format. The footprint will be added to the planned acquisitions map in the Montana Lidar Inventory.

The Montana Lidar Inventory also includes a collaboration tool. Users (open to anyone) can draw priority areas of interest (AOIs). Overlapping AOIs indicate potential for collaboration and partnership. Ideally, organizations should partner, pool available funds, and jointly apply for 3D Elevation Program funding to maximize the extent and quality level that can be collected. The MEWG and the Montana State Library can assist throughout the process.

Recommendation 2: Develop a 3DEP BAA application template that cites the Montana Lidar Plan. This template will expedite application development and demonstrate that Montana is coordinated and has a plan. Similarly, develop a Montana lidar contract template for projects that cannot be conducted through 3DEP (or are not awarded). This contract will ensure consistency across future acquisitions.

Recommendation 3: Task the MEWG with actively pursuing partnership opportunities when new collections are in the early planning phase or where there are overlapping priority areas of interest.

Recommendation 4: Task the MEWG with providing technical assistance and review of 3DEP BAA applications and lidar acquisition agreements in Montana.

Annual Lidar Acquisition Planning Calendar		
January	**February** 1st – State IT Budget Requests Due to SITSD (Biennial – even years) 15th – MLIA Grant Program Applications Due (Annual) 28th – Transmittal of General Bills in Montana Legislature to Other Chamber (Biennial – odd years) Identify Priority Areas	**March** Identify Priority Areas
April 1st – Montana Land Information Plan Grant/Funding Priority Discussions Begin Acquisition Planning Meeting for Fall 3DEP BAA Data Acquisition (no snow/no leaves)	**May** 10th – NRCS Lidar Planning for Areas of Interest (Annual) 15th – Announcement of MLIA Grant Funding Prioritization (Annual) Acquisition Planning/Partner Identification Data Acquisition (no snow/no leaves)	**June** 30th – End of Montana State Fiscal Year (Annual) Acquisition Planning/Partner Identification Data Acquisition (no snow/no leaves)
July 1st – Start of Montana State Fiscal Year (Annual) Acquisition Planning/Partner Identification	**August** 22nd – USGS Public Webinar for Broad Agency Announcement (BAA) Submissions (Annual) 22nd – USGS Issues BAA for 3D Elevation Program (3DEP) Acquisition Planning	**September** 30th – End of Federal Fiscal Year (Annual) Acquisition Planning
October 1st – Start of Federal Fiscal Year BAA Proposals Due (Annual) Data Acquisition (no snow/no leaves)	**November** Data Acquisition (no snow/no leaves)	**December**
Dates Vary: – Federal Emergency Management Agency/Montana DNRC Lidar Requests – USDA Forest Service Lidar Requests		

Table 4. *Important dates to consider when identifying partnerships and planning for lidar acquisitions.*

Technical Specifications and Standard for Acquisition

To be inclusive of stakeholders and maximize the number of uses and benefits of lidar, the Montana Elevation Working Group recommends all new lidar collections be acquired at Quality Level 1 (QL1), as described in the USGS Lidar Base Specification Version 1.3 (https://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf).

Quality Level 1 (QL1) is recommended over Quality Level 2 (QL2) to better capture features of interest (e.g., streams and buildings). The accuracy of QL1 and QL2 are the same, but the finer pulse spacing and higher pulse density of QL1 increases the potential for "hits" on feature edges. For example, a higher density point cloud leads to better identification and defining of structures and determination of lowest adjacent grade (important to DNRC for flood-risk mapping). QL1 is also important for vegetation characterization (important to USDA Forest Service, NRCS, and the Montana Natural Heritage Program). The USDA's *National Lidar Strategy: Lidar Acquisition Specifications for Forestry Applications* states QL1 provides the ideal specifications for forestry related applications. Other western states (e.g., Idaho, Washington, and Oregon) have also developed statewide lidar plans that recommend QL1 acquisition.

Recommended:

Quality Level 1	*DEM Cell Size*	*Aggregate Nominal Pulse Spacing*	*Aggregate Nominal Pulse Density*	*Absolute Vertical Accuracy* *$RMSE_z$ (nonvegetated)*	*Relative Vertical Accuracy* *(repeatability)* *$RMSD_z$*
Topo Lidar	*1 m* *(3 foot)* *0.5 m (1.5 foot) DEM possible*	*0.35 m*	*8 pls/m^2*	*0.1 m*	*0.06 m*

Table 5. *Montana's recommended lidar quality level.*

Required:

Quality Level 2	*DEM Cell Size*	*Aggregate Nominal Pulse Spacing*	*Aggregate Nominal Pulse Density*	*Absolute Vertical Accuracy* *$RMSE_z$ (nonvegetated)*	*Relative Vertical Accuracy* *(repeatability)* *$RMSD_z$*
Topo Lidar	*1 m* *(3 foot)*	*0.71 m*	*2 pls/m^2*	*0.1 m*	*0.06 m*

Table 6. *Montana's required lidar quality level.*

All lidar data and derivative products should be produced in compliance with USGS Lidar Base Specification Version 1.3 (or most recent version). These lidar specifications are required baseline specifications. A summary of specifications is provided in **Appendix C** and a summarized list of deliverables are provided below:

- Bare-earth digital elevation model
- Hillshade raster
- First return (highest hit) surface model
- Hydro-flattened digital elevation model (also recommended: hydro-enforced)
- Break lines
- Intensity images
- Survey report
- Ground control and calibration points
- Aircraft trajectory data
- LAS Dataset (*.lasd*) for the entire footprint extent
- All spatial data should be in the Montana State Plane Coordinate System: NAD83 (2011), NAVD88, GEOID12B, meters
- All-return classified point cloud
- Formal, FGDC-compliant metadata as specified in USGS Lidar Base Specification
- Tiling index and footprint boundary in shapefile format
    - In addition to tiling, products should be mosaicked to the entire project extent when feasible, or to 1:24,000 USGS quadrangle extents if the project area is large (e.g, countywide acquisitions). A file format that performs efficiently at large size should be used for full project extent mosaics (recommend: *.img*).
- Consistent organization, file directory, and naming convention

Maintenance and Dissemination

Montana lidar holdings are currently scattered amongst multiple federal, state, county, and city organizations. The data are not readily available across agencies or to the public. In most cases, the requestor needs to contact the organization that originally acquired the data and oftentimes an external drive then needs to be mailed to have the data transferred. This approach to data maintenance is burdensome on the requestor and the distributor.

Members of the MEWG recognize the Montana State Library (MSL) as the logical state agency for developing and maintaining a repository for lidar data. Making information readily available is at MSL's core. *The State Library's mission is to help all organizations, communities, and Montanans thrive through excellent library resources and services.* The Montana State Library Commission is authorized to provide standards and consistent collection and maintenance of commonly available land information pursuant to section 90-1-402, MCA; to maintain a natural resource information system pursuant to section 90-15-101, MCA; and to maintain a water information system pursuant to section 90-15-305, MCA.

In 2018, the Montana Natural Resources and Conservation Service (NRCS) partnered to provide MSL with seed money to develop a pilot lidar repository for NRCS holdings. The State Library retained server space at the Montana State Data Center in Helena (with replication to the Miles City Data Center) and began processing and storing NRCS lidar data. Recognizing the greater state need, storage of lidar data from other agencies is also in progress.

Lidar storage needs are tremendous. Preliminary estimates (notably, based on the small sample size of the existing lidar collection) suggest that storage of statewide lidar and derived products would conservatively be 500 TB (~3.5 GB/sq mi). To put this number in perspective, it is more terabytes of data than all other digital holdings at the State Library combined. Additionally, one realization of the pilot project is that data storage needs are two-fold: 1. archiving of the original deliverables from the vendor; and 2. storing data that has been readied for download (e.g., additional "value-added" processing has been completed, such as mosaicking and projecting data to the State Plane Coordinate System). Furthermore, the size of data from future lidar acquisitions is expected to increase as the technology continues to advance (higher quality data and, thus, bigger data, will become the norm).

Recommendation 5: The Montana State Library should seek IT budget increases to meet the tremendous data storage needs of a lidar repository. The storage cannot be assumed without additional resources.

Much effort is going into organizing and processing past acquisitions into a consistent format for public distribution. A guiding principle of the Montana lidar repository is to reduce time-intensive processing steps being duplicated by multiple stakeholders. For example, lidar is commonly delivered in tiles. The purpose of the tiling scheme is primarily to provide a manageable file size; however, the tiles are cumbersome to work with on a project level because of their small spatial extent. Oftentimes, users will mosaic the tiles together to create a single raster of their project area. Preprocessing the data and staging it for download adds value that saves stakeholders time and resources. The following is a list of value-added products recommended for inclusion with historic projects in the Montana lidar repository:

- All rasters (bare-earth DEM, highest hit surface elevation model, hillshade, etc.) mosaicked to the entire project footprint extent, or to 7.5 Minute (1:24,000) quadrangle extents, if the project area is large (e.g, countywide acquisitions).
- LAS Dataset for the entire footprint extent.
- All spatial data in the Montana State Plane Coordinate System (NAD83 2011, NAVD88, GEOID12B, U.S. Survey Foot) to match the standard for other Montana GIS datasets.
- Highest-hit (surface) elevation model.
- Consistent file formats available across projects.
- File formats that perform well at large size (e.g., .img), in addition to TIFF or ESRI GRID files.
- Consistent organization, file directory, and naming convention (**Figure 8**).

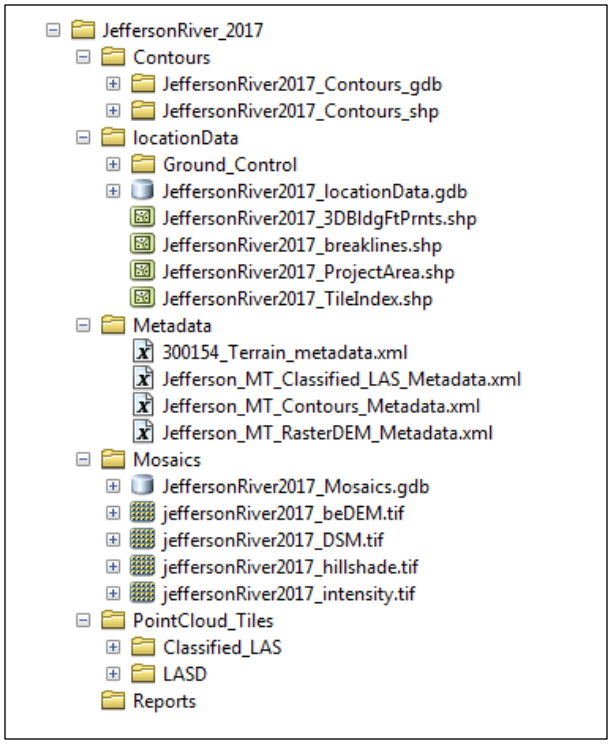


Figure 8. *An example of the file structure used for projects in the Montana lidar repository at the Montana State Library.*

Value-added processing primarily applies to past acquisitions. Ideally, future acquisitions will include these same products as deliverables (see "Technical Specification and Standard for Acquisition" and **Appendix C**).

Recommendation 6: Continue to develop a Montana lidar repository at the Montana State Library that will become the primary source for lidar data and derived products in the state. Expand the Montana Lidar Inventory to become a lidar viewer and download platform (for example, see the Oregon Lidar Viewer at: https://gis.dogami.oregon.gov/maps/lidarviewer/).

Cost & Funding Approach

Existing business uses and potential benefits of statewide lidar are many, but the dollars needed to acquire it statewide are staggering. In 2014, the National Enhanced Elevation Assessment estimated Montana statewide Quality Level 1 collection at $80 million (Carswell, 2014). However, the cost of lidar has gone down since this publication. **Table 7** uses a rate of $350 per square mile as an estimate for acquiring QL1 lidar for large project areas (e.g., ~2,500 mi^2).

Description	Square Miles	Percent of MT Total Area	Cost based on $350/$mi^2$
Lidar needed to reach the goal of the Montana Lidar Plan (complete coverage, with all new lidar acquired at QL1).	100,000	68	$35 million
Largest sized Montana county (Beaverhead)	5,573	3.8	$2 million
Median sized Montana county (Dawson)	2,384	1.6	$835,000
Smallest sized Montana county (Silver Bow)	718	0.5	$250,000

Table 7. *The cost of lidar based on a $350/$mi^2$ estimate for Quality Level 1. The area of Montana is 147,000 mi^2. Figures in the last column have been rounded for convenience.*

Currently, no state funding is budgeted through the legislature for acquiring lidar data. Other states (e.g., Oregon, Washington, and California) have lidar programs or funding established through legislation. For example, in Oregon, *"An initial $2 million seed capital investment by the Oregon Legislature has since been leveraged into more than $19 million of lidar acquisition" (from the Oregon Department of Geology and Mineral Industries, Oregon Lidar Consortium).*

To achieve statewide lidar coverage by the end of 2023, the MEWG proposes to leverage partnerships and funding available through FEMA, NRCS, the USGS 3DEP program, and other interested entities as opportunities arise. By October 2019, the MEWG proposes to jumpstart the endeavor by submitting a multi-county 3DEP BAA that potentially leverages funds from FEMA (provided to the DNRC); NRCS (provided to the Montana NRCS Office); state agencies (MSL, Montana Bureau of Mines and Geology, Montana Department of Transportation, and others); and potentially additional entities, such as county and local governments. **Table 8** is a hypothetical, though realistic, funding scenario. Similar countywide 3DEP BAA applications would be pursued in subsequent years.

Total Estimated Project Cost *(from previous page)*:		$937,500.00	
Funding Partner(s)			**% Cost Share for 3DEP Base Data**
Name(s)	**Type**	**Proposed Contribution for Lidar Data Acquisition, Processing, QA/QC**	
Montana DNRC Floodplain Management Program (provided by FEMA)	Nonfederal	$250000.00	
Montana Bureau of Mines and Geology	Nonfederal	$1500.00	
NRCS (Montana office)	Federal	$250000.00	
Montana State Library	Nonfederal	$1500.00	
USDA Forest Service (Montana office)	Federal	$50000.00	
Missoula County	Nonfederal	$10000.00	
Trout Unlimited	Nonfederal	$1500.00	
Montana Department of Environmental Quality	Nonfederal	$15000.00	
	Choose One	$	
	Choose One	$	
Funding Partner Totals (*from above*)		$579,500.00	62%
Funds Requested from 3DEP		$358,000.00	38%

Table 8. *A hypothetical funding scenario for acquiring lidar for an average-sized Montana county at Quality Level 1.*

Recommendation 7: Submit a countywide or larger 3DEP BAA application by October 2019. Continue to submit 3DEP applications in subsequent years. Appendix D provides guidance for 3DEP proposals.

Recommendation 8: Investigate the potential for the Montana State Library to accept funds from other entities and develop cooperative agreements/MOUs for lidar acquisitions. The intent of this recommendation is to function as a consortium, pooling resources to achieve a common goal.

Recommendation 9: Conduct outreach on the Montana Lidar Plan, particularly focused on identifying and forming partnerships.

Recommendation 10: Identify and engage constituents with an interest in championing legislation to make a seed capital investment in lidar.

Known Risks to Plan Execution

- Resources required for the functioning of the MEWG are currently limited to the volunteered time of its membership for meetings, research, documentation, and the execution of project tasks.

- At this time, State of Montana funding from the legislature for elevation/lidar data is non-existent, nor requested. The source of most funding going towards lidar acquisitions is federal dollars (FEMA, NRCS, and USFS, in that order). State and local dollars are needed to maximize the 3D Elevation Program cost-sharing.

- The infrastructure necessary to support storage and data access requirements for statewide lidar is substantial and cannot be assumed without financial support. Initial seed money was provided by the USDA NRCS; however, these funds were intended for a pilot project focused primarily on NRCS lidar holdings. Other states and the USGS have used a data and management cost estimate ranging from 5% (USGS) to 15% (Oregon Lidar Consortium) of the total project cost. It is unclear if 5% is an appropriate estimate for Montana.

- To date, the largest amount of funding available for lidar acquisition in Montana has come from FEMA through the Montana Department of Natural Resources and Conservation for flood-risk management. DNRC is currently managing its own lidar contracts, and participation in the 3D Elevation Program for cost sharing is uncertain. A pilot/demonstration project should be conducted to demonstrate the value of 3DEP and the Geospatial Product and Services Contract (GPSC) to Montana.

The Montana Lidar Plan will continue to evolve as lidar technology advances, specifications change, funding sources develop, and lessons are learned. The Plan will be reviewed by the Montana Elevation Working Group and updated by the Montana State Library on an annual basis.

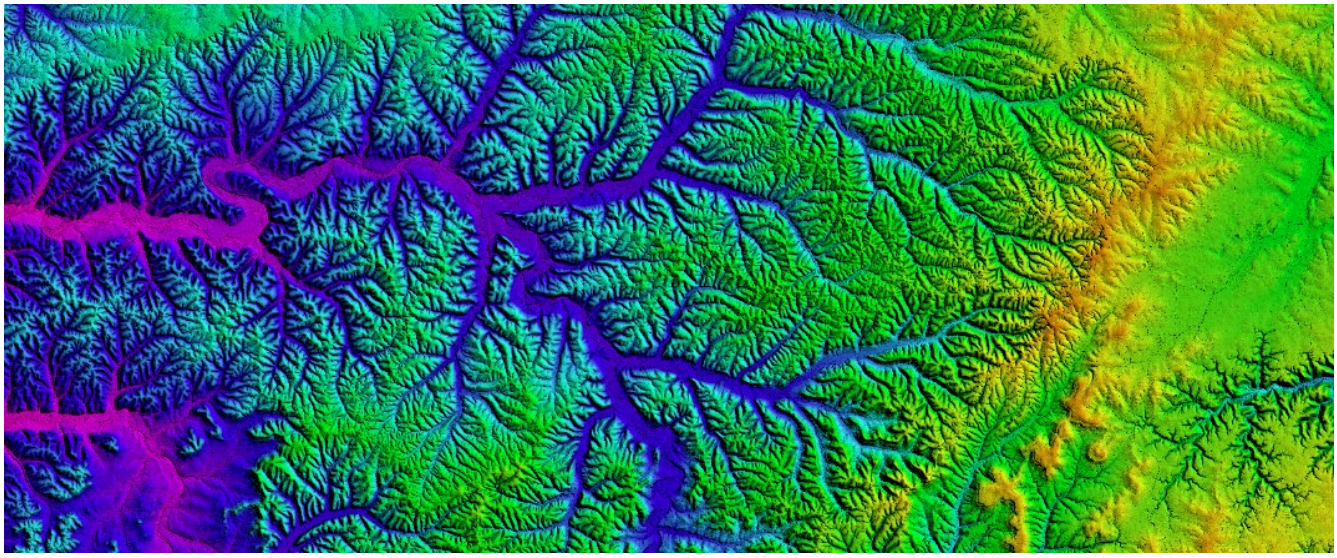


Image courtesy of Atlantic.

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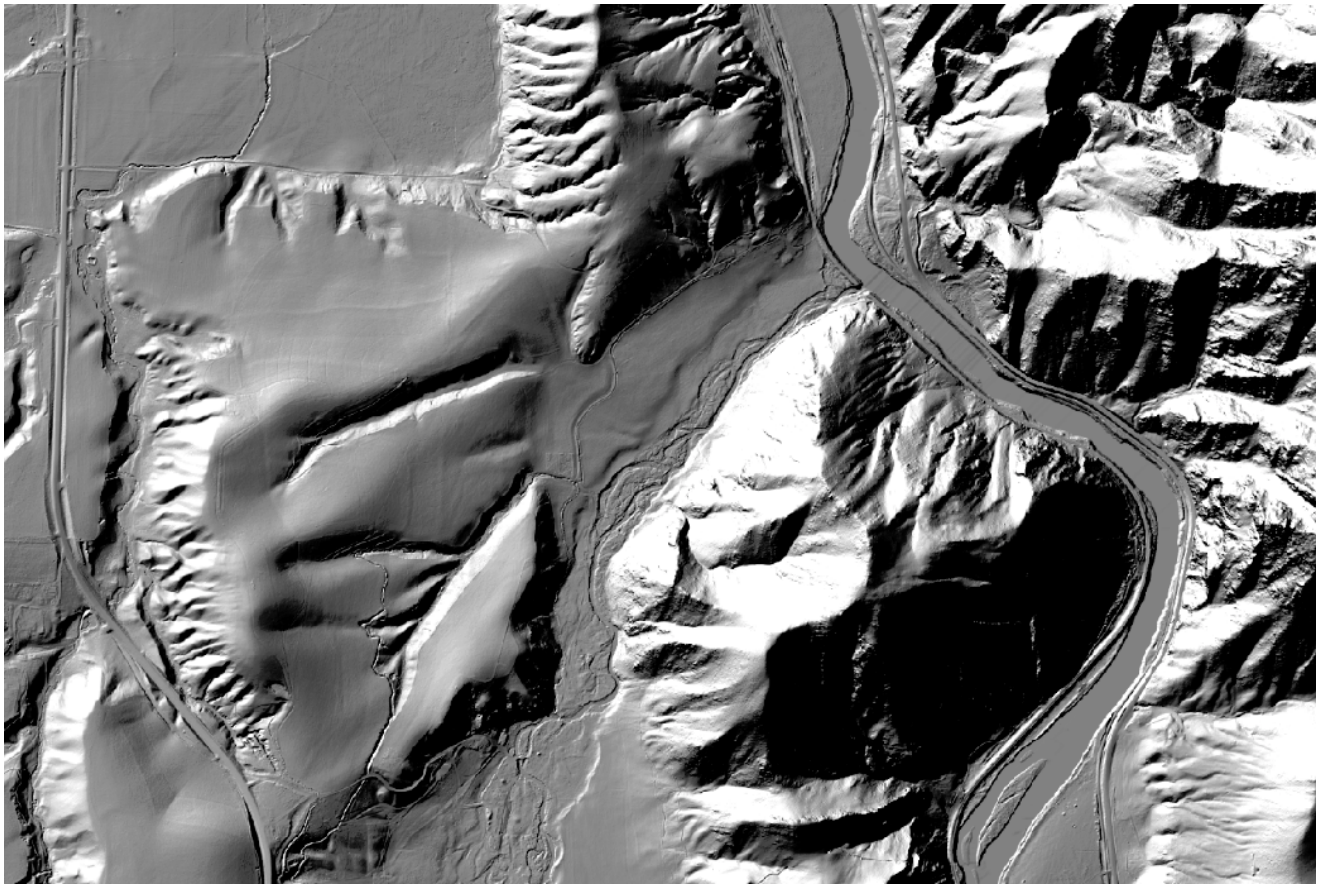


This hillshade depicts the Jefferson River along Highway 2 as it enters the canyon between LaHood and Lewis and Clark Caverns State Park. Image courtesy of Montana State Library.

Appendix A – Montana Sector, Agency, and Primary Use of Lidar

The table reflects MEWG participants and is not an exhaustive list of lidar uses in Montana. The table is summarized as a graphic in Figure 2.

Sector	Agency/Organization	Primary Lidar Use
Private	Bridger Bowl Ski Area	• Terrain modeling, ski slopes, new ski areas • Avalanche-hazard mapping *(potential use)*
Private	Northwestern Energy	• Energy siting *(assumed use)* • Tree assessment/removal *(assumed use)*
Private	Pioneer Technical Services, Inc.	• Abandoned mine reclamation • Environmental remediation • Water resources management • Infrastructure/municipal
Private	Stahly Engineering & Associates, Inc.	• Infrastructure design, construction, and maintenance • Survey and ground modeling
Nonprofit	The Nature Conservancy	• Conservation planning
Nonprofit	Yellowstone Ecological Research Center	• Height, shape, and height to crown of trees
Nonprofit	The Craighead Institute	• Mapping wildlife habitat and potential movement corridors
Tribal/Private	Northern Engineering and Consulting, Inc.	• Accurate elevation data for tribes and resiliency planning • Stormwater infrastructure • Tribal transportation planning • Surveying
Tribal	Tribal Nations (seven reservations across MT)	• Water supply: municipal, rural, industrial, and irrigation • Tribal transportation planning and design • Renewable energy, particularly wind • Infrastructure and construction management
City	City of Great Falls	• Flood-risk mapping • Improved contour maps • Private ventures • Transportation and sidewalk design *(potential use)* • Building footprints *(potential use)*
County/City	Lewis and Clark County / City of Helena	• Flood-risk mapping and hydrologic modeling • Public works
County	Missoula County	• Flood-risk mapping • Inundation mapping (detailed elevation data is used during flooding events)
County	Ravalli County	• Floodplain analysis
University	Montana Bureau of Mines and Geology	• Geologic and natural-hazards mapping • Fault-hazard mapping • Hydrologic and hydraulic modeling of groundwater for development

		• Groundwater modeling • Water resources investigations and modeling
University	Montana State University - Earth Sciences Department	• Education and training • Earth sciences research • Undergraduate and graduate course material
University	Montana Technological University	• Mining • Geophysical engineering • Topographic research, particularly landslides
University	Montana Natural Heritage Program	• Land cover mapping • Species habitat mapping • Wetland mapping
University	University of Montana	• Education and training • Land cover mapping • Geomorphology
State	Montana State Library	• Mapping surface water (hydrography database) • Structures database • Control point database
State	Montana Department of Environmental Quality	• Hydrologic modeling, particularly water quality • Engineering and design • Remediation • Mining and reclamation • Landfill and waste management • Archeology and cultural resources • Superfund sites • Stormwater modeling • Wetland mapping
State	Montana Disaster and Emergency Services	• Disaster response *(potential use)* • Community resiliency *(potential use)*
State	Montana Department of Natural Resources and Conservation	• Flood-risk mapping • Mapping of riverine areas and water resources management • Dam and levee safety • State forest health *(potential use)* • Fire risk/fuels *(potential use)*
State	Montana Department of Justice Natural Resource Damage Program	• Natural resources damage recovery and planning • Topographic and geophysical properties to support river restoration activities
State	Montana Department of Transportation	• Transportation and infrastructure design • Bridge design and construction • Stormwater modeling • Cut-and-fill analysis
State	Montana Fish, Wildlife, and Parks	• Fish and wildlife habitat mapping *(potential use)*

State	Montana State Historic Preservation Office	• Locating/preserving cultural resources *(potential use)*
Federal	USDA Natural Resources Conservation Service	• Land cover mapping • Vegetation structure mapping, e.g., for sage grouse • Watershed boundary delineation • Wetland mapping • Natural resources and conservation planning
Federal	USDA Forest Service	• Vegetation characterization • Tree heights, forest structure, forest inventory parameters • Hydrologic and terrain modeling
Federal	Montana United States Geological Survey	• Hydrography and water resources • Flood mapping • Wildlife habitat modeling • Detailed topographic maps

Appendix B – Montana Elevation Working Group Charter

November 2, 2018

Purpose and Scope:
The Montana Elevation Working Group (MEWG) meets regularly to communicate, plan, and execute initiatives aimed at improving efficiencies and standardizing procedures related to the collection, maintenance, and dissemination of high-resolution elevation data.

The MEWG recognizes as a first task the need to develop a Montana Lidar Plan that sets the path for statewide lidar acquisition and coordination. The MEWG further recognizes that statewide lidar is a long-term goal (5-10 years) with significant challenges to address regarding consistency (e.g., year of acquisition, quality level) and reacquisition on a regular basis. For these reasons, the group identifies itself with "elevation," as opposed to "lidar," and will identify future tasks accordingly to meet the elevation data needs of Montana's stakeholders and partners.

Meeting Frequency:
Meetings will occur approximately monthly (2 hours each) through February 2019 to develop the Montana Lidar Plan. Meeting frequency going forward will vary based on identified tasks, but it is expected to be approximately twice per year. The frequency and duration of meetings will be reevaluated regularly.

Resources:
Resources required for the functioning of the MEWG will be the volunteered time of its membership for meetings, research, documentation, and the execution of project tasks.

Members & Roles:
All meetings are open to anyone who has an interest. Membership is generally grouped into "active participants" and "recipients":

1. Active participants (see Table): actively attend meetings, provide guidance and input on state elevation needs, develop content, review documents, identify objectives, and execute tasks, among other duties. Active participants sign this charter, indicating a larger time commitment than recipients.
2. Recipients: want to be kept informed and receive all meeting invites and notes but generally do not guide decisions or execute tasks.

Leadership Structure:
The Montana Elevation Working Group is led by the Montana State Library:

Chair
Troy Blandford, Water Information System Manager
Montana State Library
P: 406.444.7930 | E: tblandford@mt.gov

Co-Chair
Erin Fashoway, State GIS Coordinator
Montana State Library
P: 406.444.9013 | E: efashoway@mt.gov

Active Participants and Roles:

Name	Organization	Major Roles/Expertise	Email:
Troy Blandford Erin Fashoway Evan Hammer	Montana State Library	○ The steward of Montana elevation data ○ Primary State coordinating body and working group lead ○ Lead agency for the Montana Lidar Plan ○ Owns & manages the application that shows what data exists and what data might be collected (ESRI web app, Montana Lidar Inventory) ○ Houses and distributes elevation data and lidar-derived products	tblandford@mt.gov efashoway@mt.gov ehammer@mt.gov
Catherine Maynard Josh Robino	Natural Resources and Conservation Service (NRCS)	○ Acquires lidar data (large areas) ○ Develops derived products as needed ○ Leads pilot project with State Library for storage and distribution platform	cmaynard@mt.gov joshua.robino@mt.usda.gov
Steve Story Katherine Shank Jamie Ellis	MT Department of Natural Resources and Conservation (DNRC)	○ Acquires lidar data (small to countywide) ○ Develops derived products as needed ○ Assists with the overall Project Management Plan and meeting coordination/communications (liaison)	sestory@mt.gov Katherine.shank@mt.gov jellis@mt.gov
Rob Ahl Steve Brown	U.S. Forest Service	○ Acquires lidar data (small to large areas) ○ Develops derived products as needed	rahl@fs.fed.us stevebrown@fs.fed.us
Jeremy Crowley Mike Stickney	Montana Bureau of Mines and Geology at Montana Tech (MBMG)	○ Acquires lidar data (small areas, project specific) ○ Develops derived products as neededs ○ Unmanned Aircraft Systems (UAV)	jcrowley2@mtech.edu mstickney@mtech.edu
Jessica Mitchell	University of Montana, Natural Heritage Program	○ Derived Products and Uses ○ Vegetation and land cover mapping	jessica.mitchell@mso.umt.edu

Steve Shivers	USGS	○ 3D Nation Program, Federal grants ○ Federal–State liaison	spshivers@usgs.gov
Wallace Gladstone	NECI, Inc.	○ Tribal coordination ○ Survey control	wallace.gladstone@neciusa.com

Appendix C – Montana Base Lidar Specification

The Montana Elevation Working Group (MEWG) recommends lidar collections be acquired at Quality Level 1 (QL1), as described in the USGS Lidar Base Specification Version 1.3 (https://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf), or the most current version.

Recommended:

Quality Level 1	*DEM Cell Size*	*Pulse Spacing*	*Nominal Pulse Density*	*Absolute Vertical Accuracy* *$RMSE_z$ (nonvegetated)*	*Relative Vertical Accuracy* *(repeatability)* *$RMSD_z$*
Topo Lidar	*0.5 m or 1 m* *(1 to 3 foot)*	*0.35 m*	*8 pls/m^2*	*0.1 m*	*0.06 m*

Required:

Quality Level 2	*DEM Cell Size*	*Nominal Pulse Spacing*	*Nominal Pulse Density*	*Absolute Vertical Accuracy* *$RMSE_z$ (nonvegetated)*	*Relative Vertical Accuracy* *(repeatability)* *$RMSD_z$*
Topo Lidar	*1 m* *(3 foot)*	*0.71 m*	*2 pls/m^2*	*0.1 m*	*0.06 m*

All lidar data and derivative products should be produced in compliance with USGS Lidar Base Specification Version 1.3. These lidar specifications are required baseline specifications. Montana does request some additional specifications. For quick reference a list of summary specifications are provided below:

SUMMARY SPECIFICATIONS

1. Coordinate System:

All spatial data products shall be delivered as:

NAD 1983 (2011) StatePlane_Montana_FIPS_2500

WKID: 6514 Authority: EPSG

Projection: Lambert_Conformal_Conic

Linear Unit: **meters**

Geographic Coordinate System: GCS_North_American_1983

Angular Unit: Degree (0.0174532925199433)

Prime Meridian: Greenwich (0.0)

Datum: D_North_American_1983

Spheroid: GRS_1980

Semimajor Axis: 6378137.0

Semiminor Axis: 6356752.314140356

Inverse Flattening: 298.25722210

Vertical Datum: NAVD 88, meters
The Geoid model used for the orthometric height will be Geoid12B or the most current.

NOTE: *A new geometric reference frame and geopotential datum is expected in 2022, and the coordinate system specification listed in this Appendix will be updated accordingly.*

2. Accuracy

Classified point cloud data in LAS format and a bare earth ground model DEM in 0.5 m (QL1) or 1-meter (QL2) resolution and in ESRI grid or GEOTIFF format.

Data Accuracy and accuracy reporting: Data collected shall meet the National Standard for Spatial Database Accuracy (NSSDA) accuracy standards. The NSSDA standards specify that vertical accuracy be reported at the 95 percent confidence level for data tested by an independent source of higher accuracy. For example, the metadata statement shall read, "Tested __ (meters, feet) vertical accuracy at 95 percent confidence level."

Accuracy of the Lidar Point Cloud Data: The Nonvegetated Vertical Accuracy (NVA) of the Lidar Point Cloud data shall be calculated against TINs derived from the final calibrated and controlled swath data. The required accuracy (ACCZ) is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 10 cm in the "open terrain" land cover category. This is a required accuracy.

Accuracy of the Derived DEM: The accuracy (ACCZ) of the derived DEM shall be calculated and reported in three (3) ways:

Root Mean Square error in Z (RMSEZ): required RMSEz is 10 cm, derived according to the USGS, i.e., based on RMSE of 10 cm in the "open terrain" land cover category. This is a required accuracy.

Nonvegetated Vertical Accuracy (NVA): The required NVA is 19.6 cm at a 95% confidence level, derived according the USGS, i.e., based on RMSE of 10 cm in the "open terrain" land cover category. This is a required accuracy.

Vegetated Vertical Accuracy (VVA): The required VVA is 29.4 cm at a 95th percentile level, derived according to ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data, i.e., based on the 95th percentile error in all land cover categories combined. This is a required accuracy.

Positional Accuracy Validation: The absolute and relative accuracy of the data, both horizontal and vertical, relative to known control, shall be verified prior to classification and subsequent product development. A detailed report of this validation is a required deliverable.

Relative Accuracy Requirements: Relative accuracy shall be ≤ 8 cm RMSDZ within individual swaths and ≤ 16 cm RMSEZ or within swath overlap (between adjacent swaths).

3. Products

The following shall be produced from the lidar data set and delivered:

a. Raw Point Cloud Data: as specified in USGS NGP Lidar specifications, page 14. (https://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf). The format of the point cloud files will be .LAS version 1.4.

b. Classified Point Cloud: as specified in USGS NGP Lidar specifications, page 14 (https://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf). The format of the classified point cloud files will be .LAS version 1.4.

c. Bare-Earth Elevation Model: as specified in USGS NGP Lidar specifications, page 15 (https://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf). The bare earth DEMs will be hydro-flattened and the file format of the delivered product will be GEOTIFF.

d. Breaklines: as specified in USGS NGP Lidar specifications (https://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf). The format of the breaklines will be ESRI shapefiles.

e. Control: Lidar shall be acquired using the control specifications USGS NGP Lidar specifications, page 15 (https://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf). The format of the ground control points will be ESRI shapefile.

- Supplemental Ground Control: Differentially corrected GPS Ground Control used to supplement the Airborne GPS positional accuracy.
- Ground Control Quality Check points: The Contractor shall collect additional Ground Control Check Points, which shall be delivered in ESRI Shapefile format.
- Checkpoints **SHALL NOT** be incorporated into the contractor's vertical solution.

f. Metadata will be compiled and included in the contract deliverables, as specified in USGS NGP Lidar specifications, page 13 (http://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf). The format of the metadata will be FGDC-compliant XML files.

g. **Report:** A report detailing the mission planning, equipment and methodology, the ground control, the calibration, classification and product generation used for the raw data, breakline collection and hydro-flattening. The report will include a QA/QC section detailing analysis, accuracy assessment, and validation of data deliverables. The report specification can be found in USGS NGP LiDAR specifications, page 13 (http://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf). The format of the report will be PDF.

Additional deliverables beyond standard USGS

h. **Surface (highest hit) Elevation Model:** The format of the surface DEMs will be GEOTIFF

i. **Bare-Earth DEM and Surface DEM covering entire project area, when feasible**: A single bare earth ground and surface model DEM which covers the entire project area in 0.5 m (QL1) or 1-meter (QL2) resolution in GEOTIFF format. Large projects are desired tiled to 7.5 minute quadrangles.

j. **Hydro-enforced DEM:** A hydro- enforced DEM (not to be confused with hydro-flattened) is desired for hydrologic modeling and updating of the National Hydrography Dataset. Hydro-enforced processing is described in Appendix 2, page 30 (https://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf). The format of the hydro-enforced DEMs will be GEOTIFF.

k. **Project Boundary:** A polygon shapefile of the project area boundary in ESRI shapefile format.

l. **Ground Control Points:** A point shapefile of all ground control points with their latitude (decimal degree), longitude (decimal degree), and orthometric height (international feet) above mean sea level using Montana State Plane NAD83 (2011) in International Feet and vertical NAVD 88, International Feet datum using Geoid 12B. The latitude, longitude, and height will be attributes of the points and the file will be ESRI shapefile format.

m. **3D Building footprints** for the project area delivered in shapefile format

n. **1-foot contours**, individually tiles from bare-earth, delivered in shapefile format

4. Tiling Scheme and Data Format:

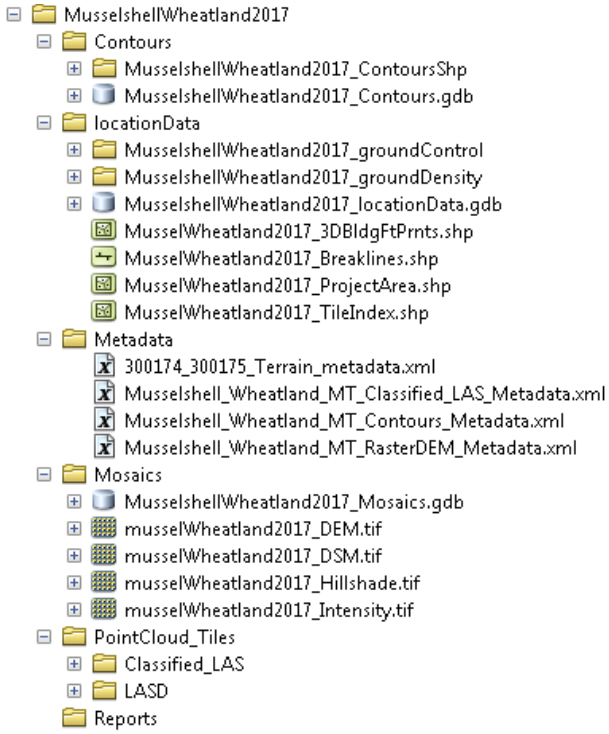
Tiled deliverables will be named, edge matched and otherwise will follow the guidance specified in USGS NGP Lidar specifications, page 14. (http://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf).

a. **Tile Coverage:** Tiles which lie completely within the project area shall be complete to the tile edges. Tiles which lie partially outside the project boundary shall be complete to the project boundary with enough overlap beyond the project boundary to ensure that no parts of the project are omitted.

b. Tile Size: Tiled deliverables shall conform to the USGS 3DEP National Tiling Index Scheme. Tiled deliverables shall edge-match seamlessly in both the horizontal and vertical. For large projects, such as countywide collections, a more manageable number of tiles (larger-sized tiles) is desired. 7.5 minute (1:24K) quadrangles have been tested for Montana and provide a good balance between number of files and individual file size. https://mslservices.mt.gov/Geographic_Information/Data/DataList/datalist_Details.aspx?did={0A09EFD4-4AEE-415E-BCC2-D4396B2BAAFC}

5. Organization, file directory, and naming convention

Deliverables must be well-organized on disk. Following is an example of a preferred file structure. The USGS National Geospatial Technical Operations Center (NGTOC) folder structure is also satisfactory.



Appendix D – Best Practices to Leverage Federal Funding Opportunities

Steps to a successful 3DEP BAA Application:

1. **Define the Team/Partners**
   a. Have defined roles to ensure that deadlines are met and that the group keeps the project focused.
   b. Ensure team/partners have a vested interest in the project.

2. **Identify the 3DEP Area of Interest**
   a. Ensure the partners' AOI are as contiguous as possible.
   b. Leverage the federal priorities in your state with your priorities to ensure the project is looked at as being usable over many agencies. Don't submit multiple BAAs in one year. One larger proposal with all entities and areas of interest represented demonstrates coordination.

3. **Understand Lidar Technology**
   a. Partners need to have a fundamental knowledge of what the technology is and what it is not.
   b. Understand the USGS Quality Levels for lidar coverage.

4. **Become Familiar with the 3DEP Program**
   a. Learn the federal priority areas. This will enhance the success of your project if you align your project with those federal priorities.

5. **Identify Business Uses and Needs for the Partners and the State**

6. **Identify and Work with a Technical Partner**
   a. The earlier the team/partners can find a technological partner, the better the application will be from a technology standpoint.
   b. The technological partner can assist with the overall estimate of the project and can help with sensor technology as well.
   c. The technological partner can assist with the formation of the AOI as well as advice on to how to best situate the AOI for maximum return on investment.