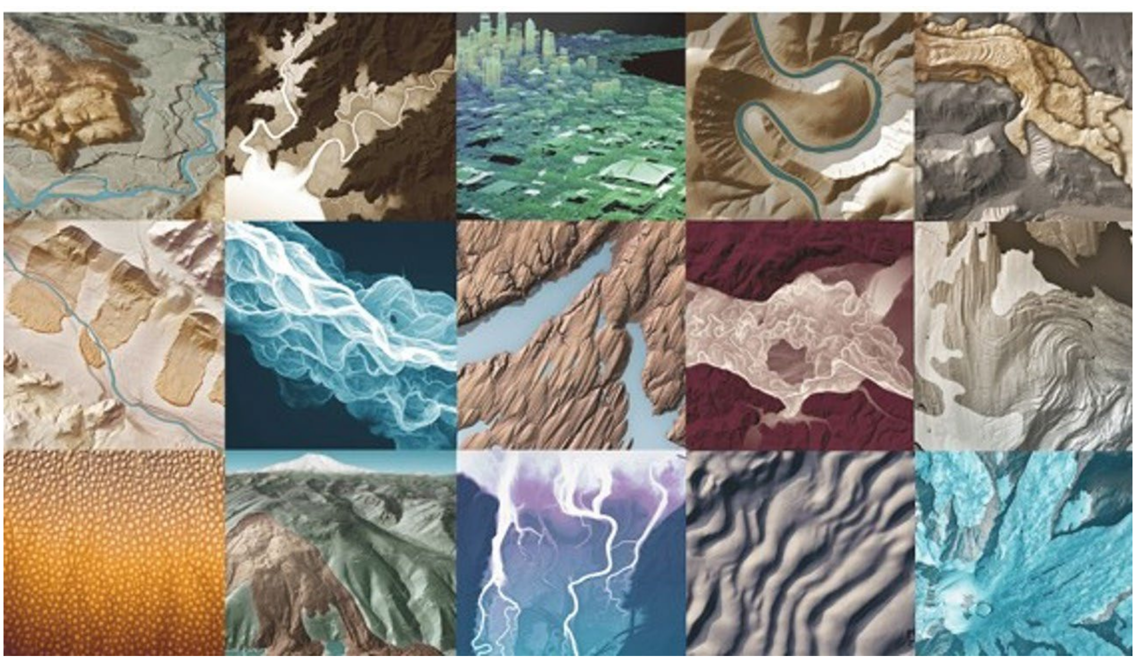
WASHINGTON STATE LIDAR PLAN



WASHINGTON STATE LIDAR PLAN

Executive Summary

The Washington State Lidar Plan was initially established in 2019 as a means to communicate to our users the benefits of this high-resolution elevation resource as well as how the State intended to complete statewide coverage. As the first coverages across the state are nearing completion, this plan is updated with goals moving forward to establish a consistent, comprehensive, and systematic strategy for repeat coverages at a minimum ten-year refresh rate. By communicating this plan with state, local, tribal, and federal partners, the aspiration is to foster collaboration on lidar collection and funding to reduce the refresh rater further and better serve Washington users. To help encourage partnership and participation, this plan also discusses the costs and resources needed to collect multiple repeat coverages and manage the growing lidar dataset.

Introduction

The objective of this report is to provide an overview of lidar in Washington State for potential users of lidar data, such as cities, counties, state agencies, federal agencies, and tribes. This report includes a summary of the applications and value of lidar data, a strategy for collecting and updating statewide lidar coverage on a consistent, reoccurring basis, and an overview of how this plan will be implemented for the state.

The State Lidar Program was created in 2016 in response to the need for consistent, high-quality lidar data for hazards identification and to fulfill a mandate to publicly distribute the data. Lidar data has a wide range of benefits and applications in addition to hazards identification, and the Lidar Program's goals have expanded to ensure lidar collected for the state meet national standards and can support state, local, tribal, and federal partners. This State Lidar Plan has several aims: 1) to communicate how the state intends to collect lidar and gain consistent, repeatable, high-quality coverage; 2) share details about lidar collection methods, specifications, and costs; 3) to standardize collection and quality assurance procedures to provide reliable data stewardship; and 4) foster collaboration and partnership. The Program aims to provide complete statewide coverage at a high resolution and to have a plan for refreshing the data moving forward.

The State Lidar Program is managed by the Washington Department of Natural Resources through the Washington Geological Survey (WGS). This plan is an interagency effort between WGS and the Washington Technology Services(WaTech) Geospatial Program. Partners from state agencies, counties, cities, tribes, and federal agencies also participated in the development of this plan.

Acknowledgment: In 2018, the National States Geographic Information Committee (NSGIC) initiated a project for states to develop formalized statewide lidar plans. Washington was one of eight states selected to participate in this project which was the catalyst for developing this plan. We appreciate their support.

Statewide Lidar Management and Organization

Lidar management at the state level is the result of interagency efforts. WGS is the technical lead for lidar and the state lidar champion. WaTech assists in plan development. The agencies co-chair the lidar Lidar Management Team. The Lidar Management Team is responsible for tasks such as identifying partners and interested groups, holding advisory meetings, obtaining feedback, and writing and updating the State Lidar Plan. As of 2023, the Planning and Coordination Team consists of:

- Abigail Gleason, Lidar Manager and State Champion, WGS
- Casey Hanell, State Geologist and Director, Lidar Program Advisor, WGS
- Joanne Markert, State Geographic Information Officer, WaTech.

Partners are critical to the development of this plan and will be key to its successful implementation. Partners participate in two meetings a year, assist with establishing priorities, identify funding options, provide feedback about the plan, and advocate for lidar in their agencies/regions. Appendix A lists past and present partner agencies and organizations. These partners comprise the Lidar Advisory Committee and represent a variety of state, local, federal, and tribal entities. Washington held its first Lidar Advisory Committee meeting in September 2018 and has continued to hold meetings on a biannual basis with meetings typically occurring in the spring and fall, to mirror planning and grant seasons.

Applications, Benefits, and Value for Washington State

Geologic mapping, hazards identification, and characterizing the terrain has long been challenging in Western Washington due to the dense vegetation. The heavy canopy occludes the ground and makes traditional mapping techniques from aerial imagery prone to significant error, or in some cases useless. The first known state lidar project occurred in 1996, and the ability for lidar to 'see through the trees' was tested over Bainbridge Island. The result was nothing less than stunning, revealing the Toe Jam Hill fault (fig. 1).

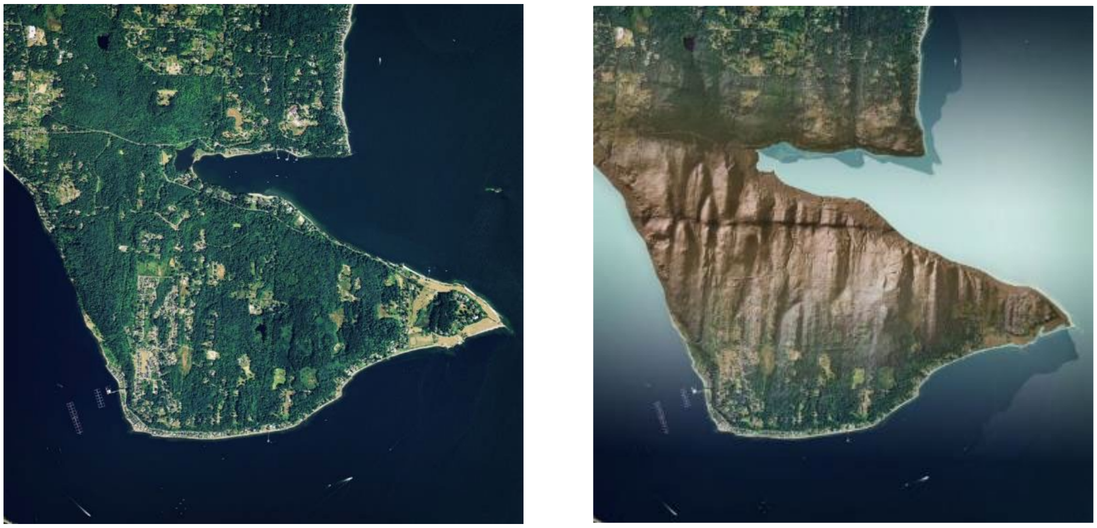


Figure 1: Bainbridge Island. The left image shows the imagery over island. The lidar imagery, to the right, reveals the fault scarp underneath the vegetation

For landslides, the comparison between traditional mapping techniques and lidar is no less significant, and the benefit for the State is tangible: landslides are common across Washington and impact the population regularly. Lidar data reveal the locations of landslides and alluvial fans for inventory mapping and provide detailed information on their features and characteristics. This information increases understanding about landslide characteristics, history, and susceptibility of a particular area to similar events in the future (fig.2).

Figure 2: Comparison of imagery and lidar data over Cedar River, King County. Lidar data reveals several landslide features beneath the vegetation

Lidar mapping has a large impact on other applications and disciplines as well. Lidar is used extensively for forest inventory to accurately measure the height of vegetation and growth patterns, as well as characterizing forest structure. Lidar is also the most accurate elevation source for deriving hydrology and understanding how water flows across the landscape. In the fall of 2018, the Lidar Management Team sent out an informal survey to state agencies and local partners and asked about their applications for lidar to gain an understanding of how lidar is used across the state. The applications are summarized in Figure 3.

In speaking to users, we've also gained an understanding of how lidar data is used for individual projects, such as site characterization for the placement of an engineered log jam to enhance salmon habitat, planning for culvert redesign, slope stability analysis for construction permitting, quantifying urban change and development, flood risk mapping, and trail development through county and city parks, to name a few.

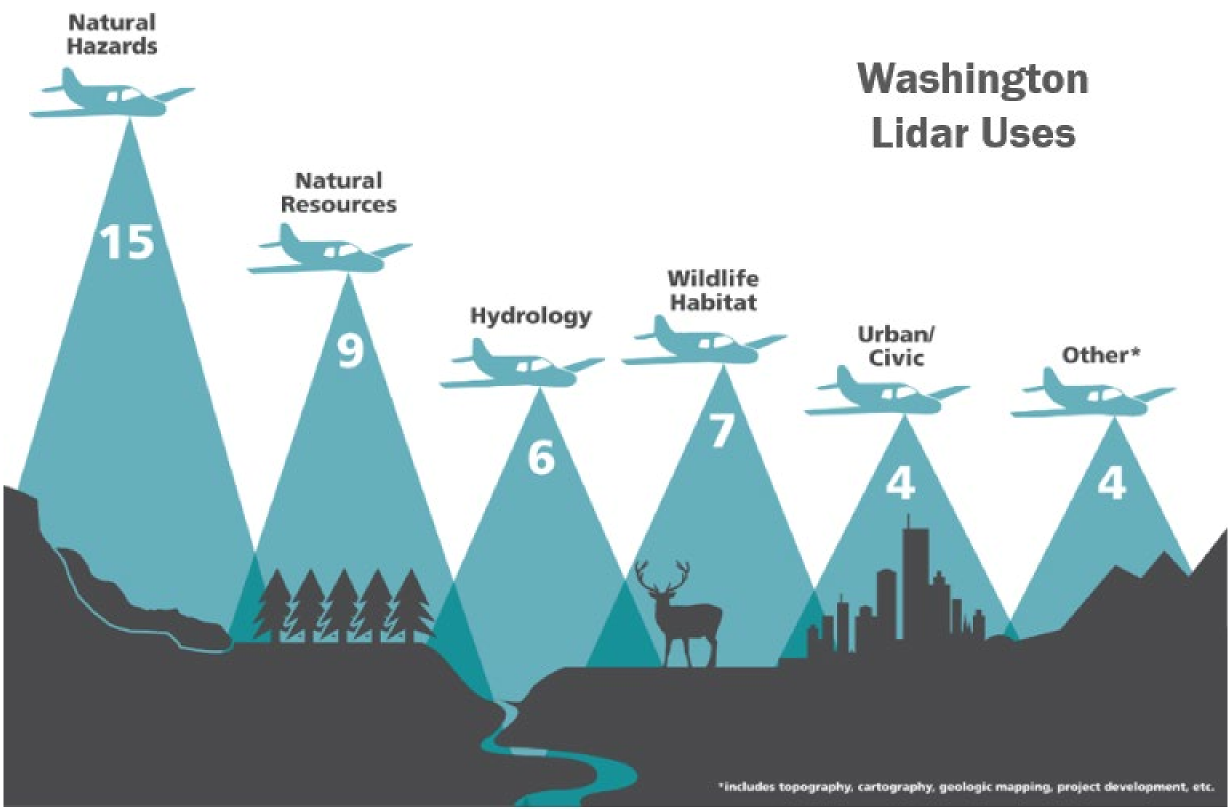


Figure 3: applications and uses of lidar data, categorized by response type

In September of 2022, the 3D Nation study[1] was published by the U.S. Geological Survey (USGS) and the National Oceanographic and Atmospheric Administration (NOAA). This was a joint study to understand

[1] Dewberry, 2022, 3D Nation Elevation Requirements and Benefits Study [accessed July 26, 2023, https://www.dewberry.com/services/geospatial-mapping-and-survey/3d-nation-elevation-requirements-and-benefits-study]

the impacts, requirements, and benefits of having high-resolution elevation and bathymetric information available across the nation. Multiple agencies and groups throughout Washington State were surveyed about their uses of high-resolution terrain data, and Table 1 below summarizes the top ten applications of elevation data that have the largest reported benefit for the State.

1. **Geologic assessment**
2. **Urban and regional planning**
3. **Flood management**
4. **Infrastructure and construction**
5. **Sea level rise and subsidence**
6. **Natural resource conservation**
7. **Homeland security and emergency management**
8. **Real Estate**
9. **Coastal zone management**
10. **Wildfire management**

Between the Lidar Program's interaction with the community and through the national survey and reporting, lidar data clearly supports a wide range of applications and touches on many aspects of our users' work and daily lives.

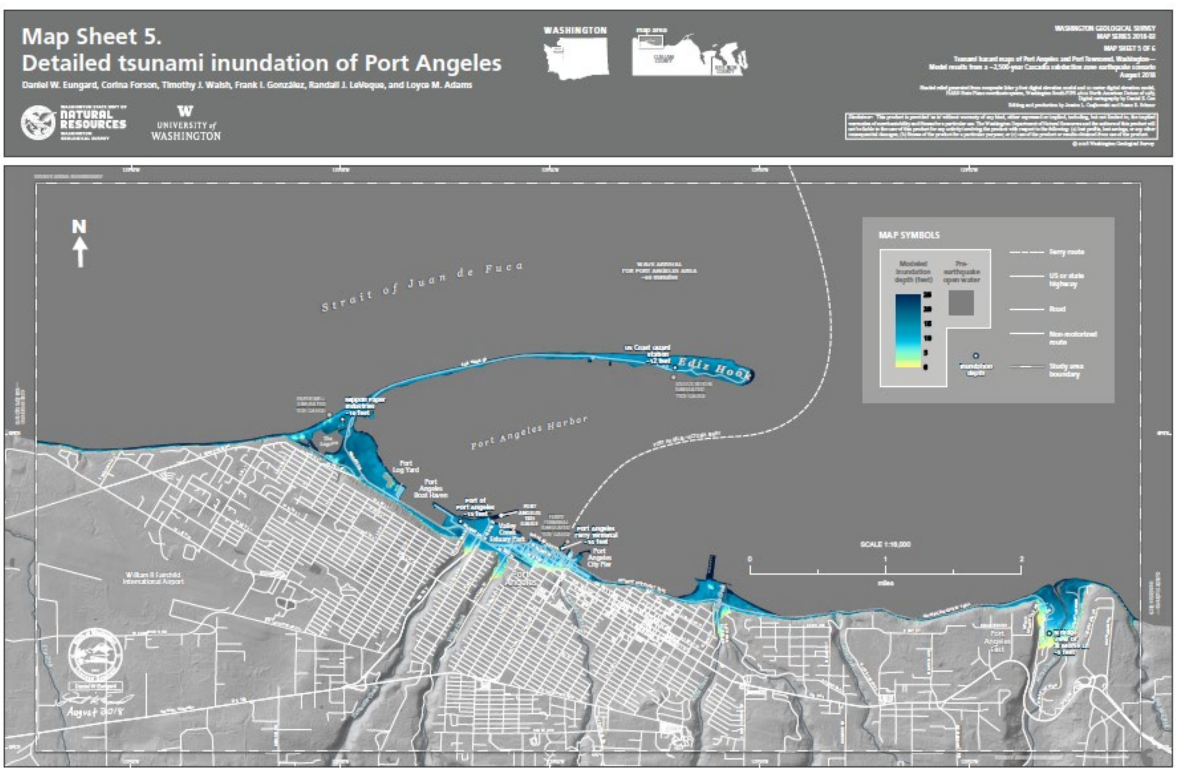


Figure 4: Detailed tsunami inundation map of Port Angeles. This map incorporates lidar data in the generation of the inundation model as well as in the basemap it is displayed upon.

Benefits

Elevation is a foundation data source used in a wide range of modeling, analysis, planning, and mapping activities. While any elevation source can be used, lidar's combination of high accuracy, high resolution, and ability to map under vegetation make it ideal for understanding complex environments. The benefit is that more accurate analysis can be achieved, targeted monitoring and management can be done, and better decisions can be made. There are now applications and workflows that require lidar be collected or available first – for example, geologic mapping in Washington requires lidar, as does FEMA flood and risk mapping. The USGS Elevation Derived Hydrology Program is predicated on the assumption that lidar be available to derive products in the conterminous US. New workflows are being developed based on the availability of lidar, sometimes making the benefits of lidar difficult to quantify as there was no comparable workflow before. Repeat coverages are now available in some places, allowing for new analyses that were unavailable on such a broad scale before. Whereas repeat spot measurements may have indicated change previously, lidar shows the change through an entire environment and can help characterize the reasons for that change. And what makes the benefits somewhat intangible also lends to the real societal benefits lidar has: the ability to help innovate, learn and do more, and in greater detail.

When talking to users and partners across the state, they qualify the benefits of lidar in terms of saved time and resources. By having lidar data before projects begin, better estimates can be made for amount of material, number of crews needed, equipment, obstacles present, etc. This in-depth planning can account for time saved in the field and even saved money by making the correct assumptions and decisions from the very start. Targeted analysis can be done to characterize sites or inventory hazards, often without needing to field verify at all, or to make a better selection of which sites to visit without the field work being random or uninformed. All of this leads to projects being completed faster and better information being disseminated to users and the public.

Value

If benefits are hard to quantify, the value of lidar, or return on investment (ROI), is even more challenging. Many benefits, such as saved time and resources, are intangible, and several of the workflows we now use were not accessible or in use before lidar became available. Nevertheless, the USGS has attempted to quantify the monetary benefits in the 2012 National Enhanced Elevation Assessment (NEEA) and more recently in the 2022 3D Nation study led jointly by the USGS and NOAA. From the 2012 study, it was estimated that fiscal benefits for Washington State from lidar were at least $9.46 million per year, based on a 'Quality Level 2' product. This was a conservative estimate at the time, and currently Washington State requires at least a 'Quality Level 1' (QL1) product, which is higher resolution and higher accuracy, meaning that the annual benefits may be greater. The 2022 3D Nation study looked at benefits for high-resolution elevation and bathymetry data and estimated the annual fiscal benefits to be at least $13.5 billion across the nation.

The 2022 study also looked at which quality level would have the highest value, as well as at what frequency lidar should be collected at to have the greatest benefit. Generally, it was found that data collected at a higher resolution and accuracy (such as Washington currently collects) and at a more frequent rate had higher net benefits and value. While this may seem counterintuitive given the high cost to collect lidar data, this finding speaks to greater benefit of having repeat coverages of lidar over the same area: users are recognizing that repeat lidar coverages at a higher accuracy allow for more varied types of analyses and work to be done, leading to more information in dynamic, complex, and localized systems.

Past Efforts

Lidar collection started in Washington in 1996. The Puget Sound Lidar Consortium (PSLC) was established to continue collection efforts, with many local partners from Kitsap, City of Seattle, Clallam and Island counties, and federal partners USGS and NASA. The goal of the PSLC was to create a lidar collection mechanism for Washington participants and host a portal to share the lidar from more than 70 collection projects across the state. The PSLC set the stage for future lidar data collection and established technical specifications and guidance. This initial work in Washington was primarily project driven, resulting in a concentration of lidar in some places and large gaps in others. Figure 5 below shows the lidar coverage in 2021, and demonstrates the 'patchwork' and inconsistent nature of lidar collection.

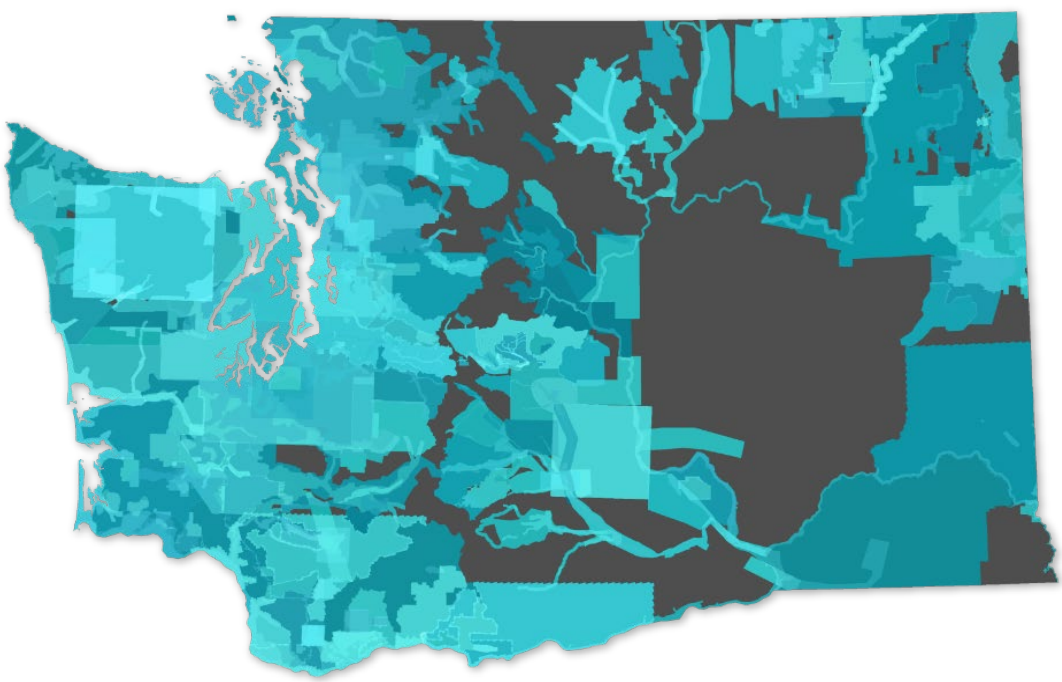


Figure 3: Washington lidar coverage in 2021, which demonstrates the project-based nature of collection until more systematic collection coverage began

In 2015 the legislature passed RCW 43.92.025, mandating that the Washington Department of Natural Resources, through the Washington Geological Survey (WGS), acquire new lidar or update deficient data, and create and maintain an efficient, publicly available database of lidar data. For the first years of the program, WGS focused on filling in the gaps and systematically collecting high-quality lidar coverage for the State. In 2019, the first version of the State Lidar Plan established the mapping requirements and specifications for the state, which informed both state and federal partners how to complete lidar mapping projects and integrate with existing coverage. Based on these collaborations and with support from local partnership, the first statewide lidar coverage for Washington is projected to be finalized in 2024.

Updating Statewide Coverage

Washington is entering the next phase of lidar collection, which will focus on lidar 'refresh', or re-collection after the first baseline dataset has been completed. While many people think of the terrain as 'static' or unchanging for long periods of time, in reality the terrain in Washington can be quite dynamic and change within a single year, especially at the local level. There are numerous examples: rivers change frequently and move within the 'channel migration zone', and remapping these areas periodically is important for understanding flood risk and regulations for development. The coast is particularly susceptible to change, as coastal erosion and sediment transport become more dynamic as the climate changes. Washington has a high number of landslides and debris flows each year, and by inventorying these features the hope is the public is armed with better information. Wildfires change the landscape on a broader scale, first by changing the structure of forests, vegetation, and structures, and often later through mechanisms of post-wildfire debris flows. As the land shifts over time, it is important document that change and how it affects the environment and the people who live there.

Lidar data has a tendency to become 'out of date' relatively quickly given its high resolution and accuracy. Re-collection of lidar showcases one of the dataset's greatest applications – change analysis (Fig. 6). If lidar is recollected at a consistent rate, it becomes an incredible tool to understand the variables that control environmental change. Older lidar datasets do not decrease in value, rather they take on a new life becoming a historical baseline, and new datasets compared to these older datasets aid in monitoring and understanding change over time. Similar to imagery, lidar also captures changes in vegetation and the built environment every two to three years. Lidar can capture change in the terrain as well, documenting volume gained or lost and give insights into how that changed occurred as well.

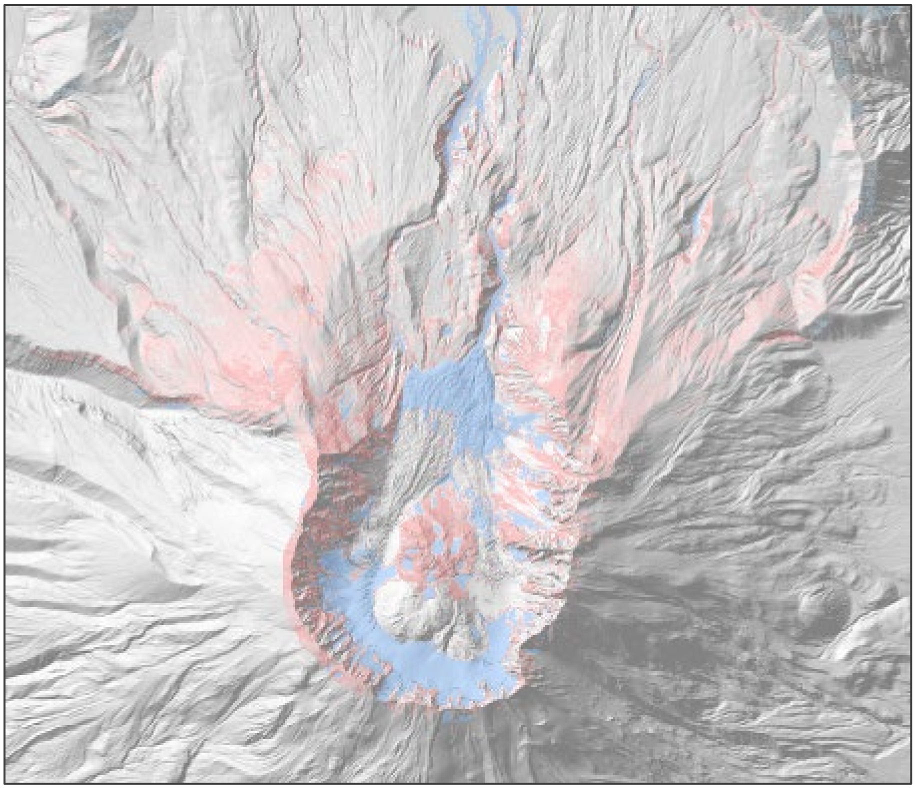


Figure 4: Lidar change detection analysis done for Mt. St. Helens shows where material was removed due to erosion (light red areas) or where material was added, such as snow and glacial growth (blue areas)

As described in the examples above, there can be a lot of dynamic change within just a few years at the local level. However, if you add up all these local changes and factor in broader change from forces like annual wildfires, it becomes economical to recollect lidar over larger portions of the state at once. Lidar has an economy of scale factor in the cost of collection. The more area collected, the lower the cost per unit area it is to collect. It can also be difficult to 'stitch' multiple datasets together to make effective models. A hydrologic model, for example, would perform better from data collected all at once across the entire region rather than by stitching multiple datasets together, even if they were collected more recently. Therefore, having one contiguous dataset for an entire region has the greater benefit overall.

What is a good rate for refresh across the state that will serve the community and capture both local and wide-scale change consistently? The Lidar Management Team tackled this question with the user group and found responses varied across the state. A refresh rate of every five years in dynamic environments, generally represented by areas west of the Cascades and in riverine systems, seemed appropriate to most respondents. A refresh rate of every ten years would be adequate in portions of eastern Washington. The 2022 3D Nation study also addressed this question and found that 63 percent of respondents' requirements would be met if their areas of interest were collected every four to five years. The Washington Geological Survey has proposed a ten-year statewide recollection rate and is seeking on-going legislative funding to support this initiative. If on-going funding is granted, a ten-year recollection rate can be achieved at minimum, and additional partnerships and grants could help reduce this recollection rate to get closer 3D Nation study goal of five years. With the continued support and federal focus on high-resolution terrain data, reducing this rate and delivering high quality elevation data to Washington users quickly seems achievable.

Lidar Collection Strategy

In developing a collection strategy for Washington State, there are several factors to consider:

- a block or regional approach ensures the strategy is organized and repeatable
- environmental constraints such as snow or leaf-off conditions affect lidar collection
- balancing funding needs to ensure state costs remain predictable and achievable
- opportunities for partnerships or grants that can be leveraged to reduce the recollection rate to less than ten years

For the 'blocks', whole counties will be acquired during a collection year. County boundaries were determined to have the most utility to the greatest number of users, though it is recognized that some users work across jurisdictions or in watersheds. Therefore, the strategy is to collect a few adjacent counties together to minimize any temporal discrepancies.

There are several ecological regions across the state that have different considerations when collecting lidar, and therefore may be collected in different seasons. For the Puget Lowlands, lidar must be collected during the 'leaf-off' period from November to mid-April to maximize the collection of ground points through the forest canopy and understory. High-elevation areas such as the Olympics and Cascades are best collected in late summer when permanent snow is at a minimum and before significant weather begins. Collections in coniferous forests also need to avoid snow conditions and have a little more flexibility into the fall. The Columbia Basin area has the greatest flexibility, however wildfire smoke must be avoided. Figure 7 shows a generalized map of the different lidar collection seasons for each of the ecological regions in the State. Mixing collections across two or more ecological regions within a year facilitates larger collections during any budget period.

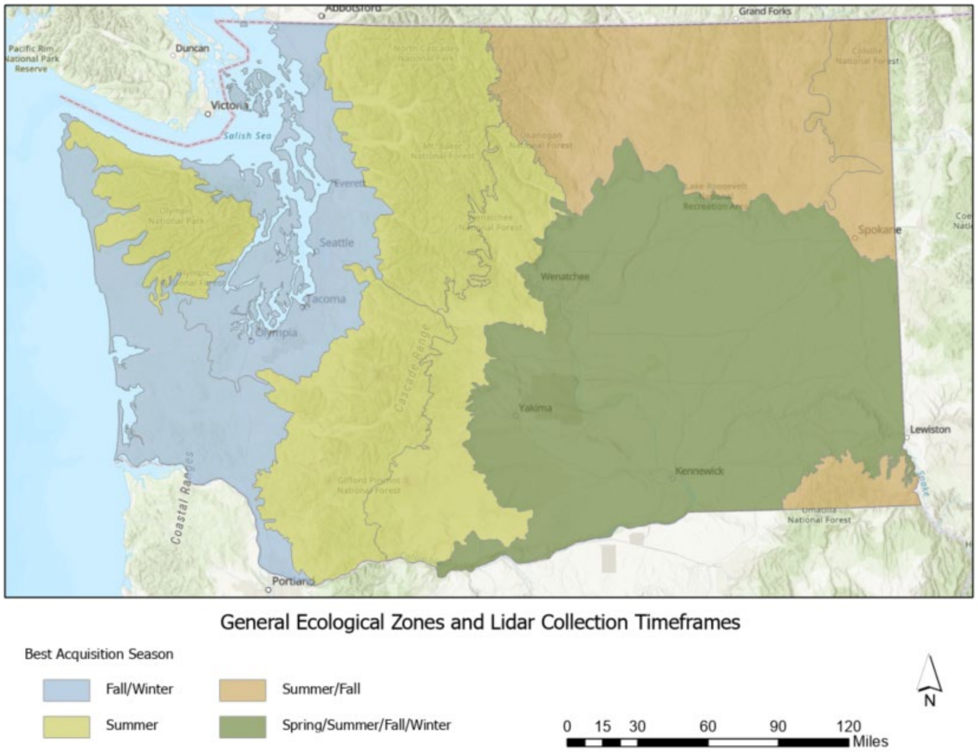


Figure 7: best lidar collection times across the state

State costs need to be balanced and predictable across a fiscal biennium. This can be a challenge, given that collection 'blocks', or counties, are quite variable in size. Collection costs also vary with the steepness of terrain and complexity of processing, for example in urban environments or along shorelines. By modeling acquisition costs and seasonal collection opportunities, counties can be grouped together to make a draft collection plan for each year. Figure 8 shows a possible pattern for collection based on a ten-year recollection rate.

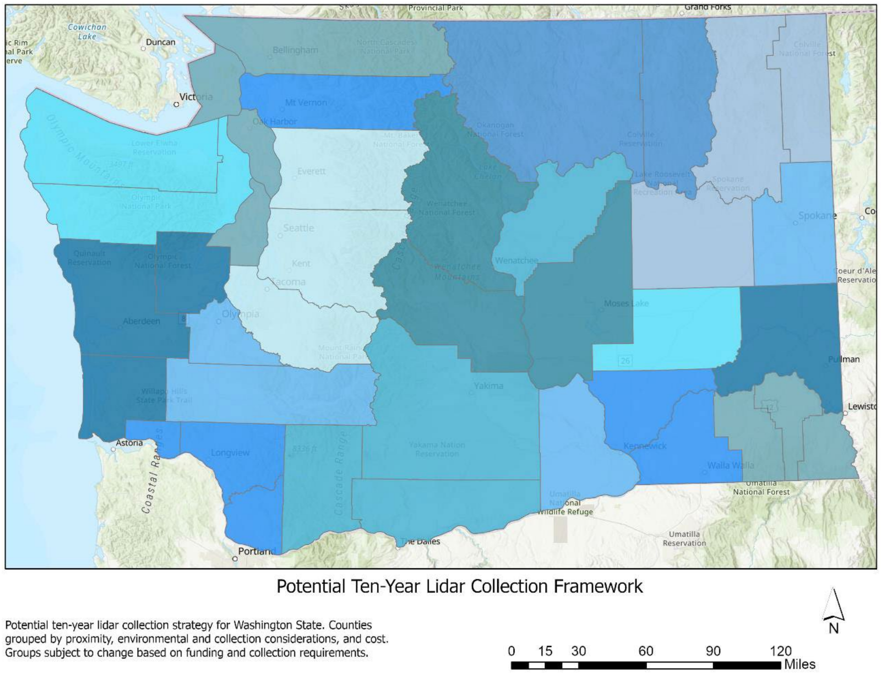


Figure 8: possible ten-year lidar collection strategy, based on grouping multiple adjacent counties and regions together to diversify collection opportunities

The Planning and Coordination Team will continue to work with the Lidar Advisory Committee to find state partnerships and grants to expand collection each year. In this way, the goal is to reduce the recollection rate to eight years, six years, or even fewer if opportunities allow. Therefore, the strategy needs to be flexible enough to be modified with different sources of funding. In this case, the collection plan would expand to include a few adjacent counties, and enough funding to add the new counties would need to be covered by the partnerships and grants. For example, if in one year the plan is to collect Clark, Cowlitz, Wahkiakum, Walla Walla, and Franklin Counties and a grant opportunity arose, the state may seek to add Pacific and Whitman. If the grant match opportunity did not cover additional collection costs in full, state partnerships could be sought to make up the difference. Figure 9 below shows a potential eight-year collection strategy that shows an example of how counties could be regrouped to reduce the recollection rate.

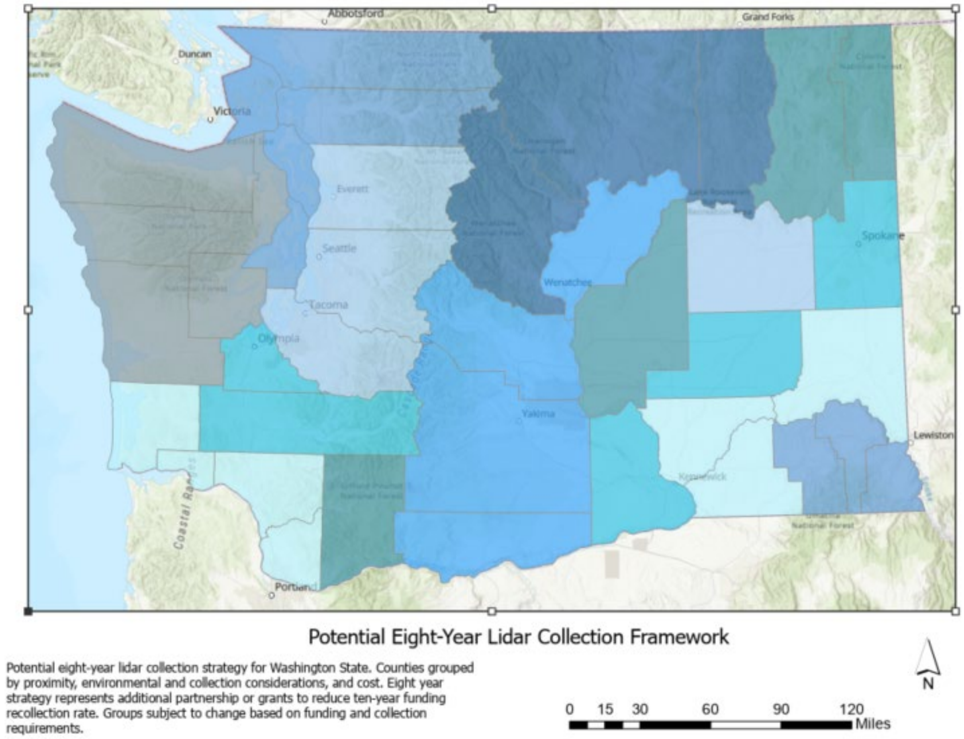


Figure 9:example of an eight-year collection strategy if grant and partner funding can be leveraged to reduce the lidar refresh rate

The maps presented here are not intended to convey a set plan. As described in the previous section, partner and grant funding may vary each year and therefore the actual collection plan will need to remain somewhat flexible. The main purpose here is to convey the goals, limitations, and considerations that will go into finalizing each year's plan, and the guiding principles that will be adhered to, with consistency in the overall strategy. Each year, the final collection area will be decided upon by the Lidar Advisory Group and published so that the community also has understanding and can predict when their areas of interest will be collected.

Bathymetric Lidar

Bathymetric lidar is becoming a significant technology for Washington State. Bathymetric lidar uses green or blue wavelengths of light to penetrate through water. Successful collection requires additional considerations beyond typical weather and ground condition constraints. The water should be as clear as possible, therefore turbidity should be monitored closely. Lower flows on a river or low tide in the ocean also increase the chances of the light reaching the bottom, as does lack of significant aquatic vegetation. While bathymetric lidar collection remains challenging in the nearshore ocean environment, good collection conditions do exist for many of Washington's rivers at some point throughout the year. Several local partners have worked with the State to collect bathymetric lidar over several rivers, including the

Skokomish, Nooksack, Naches, Green, Entiat, and Cowlitz rivers. Additional work has been done on the Nisqually, Hoh, Wenatchee, and Dungeness rivers in the past few years by private groups, underscoring the importance of this methodology to support work on these rivers.

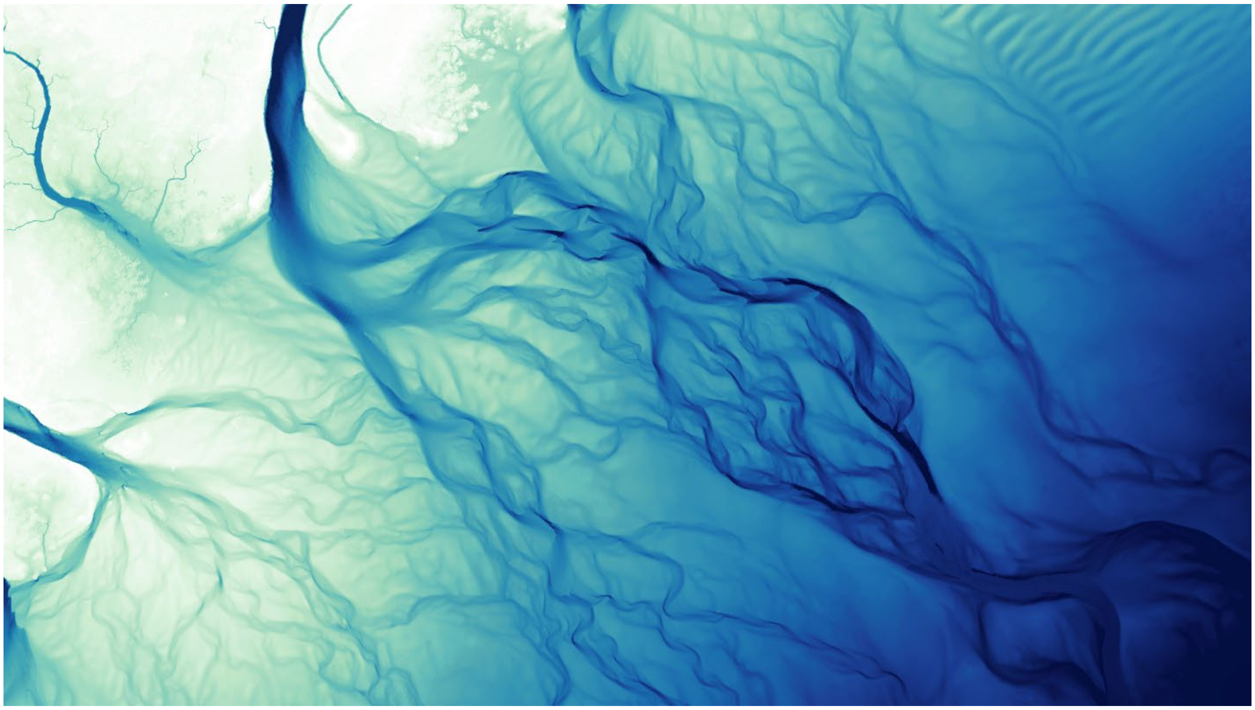


Figure 10: Bathymetric lidar collection of the Nooksack River delta, showing the active channels and sediment ripples

The applications of bathymetric lidar are numerous, including:

- flood modeling and mitigation
- channel morphology modeling
- flow rate modeling
- salmon restoration planning
- sediment management

Despite the potential of bathymetric lidar, there are areas where it is limited due to collection conditions or depth. In those areas, supplemental sonar may be needed to complete a river or nearshore profile.

The 2022 3D Nation study also showed the need for bathymetric data, particularly in the inland and nearshore environments. The USGS is developing a bathymetric collection program, with pilot studies occurring in 2023. Their plan will be to offer bathymetric collection and support through a grant process similar to the 3D Elevation Program, starting perhaps as early as fall 2024.

Thus far, bathymetric lidar collection in Washington has been opportunistic. The work has been project-based and dependent on direct partnerships. Part of the reason for this is cost– it remains quite expensive in comparison to other elevation collection methods because a plane needs to fly much slower and at a lower altitude to penetrate the water column and ensure ground returns are measured. Sonar work is generally done from a boat, or sometimes manual measurements need to be taken to fill in the deepest parts of a river or lake where aquatic vegetation occludes the bottom. Collection conditions and timing needed for each river or lake may be unique, even for tributaries or portions of the same river, as turbidity and flow rates vary. Some attempts have been made to collect broader portions of the nearshore environment, and with mixed results. Tide conditions vary dramatically by location within the Puget Sound, and the outer coast has high turbidity and wave action.

Despite the collection costs and challenges, the Lidar Program continues to work with partners as their needs require bathymetric data, and the program continues to apply for grants as opportunities arise to provide more of this data to the state.

Implementation

To implement the lidar collection strategy, funding, resources, and opportunities need to be identified. Thus far, the Lidar Program has used a mixture of state funding, grants, partnerships, and contract management methods to complete collections and manage the data. This section describes current funding sources and implementation methods.

State Funding

WGS has a set funding amount per biennium dedicated to lidar collection, which is identified as the primary “core” funding for the State. This core funding was set in 2015 with RCW 43.92.025 to focus on mapping landslides and hazards. State agencies quickly realized that lidar was needed statewide, and that regular re-collections would enhance the utility of lidar mapping for all applications. To meet the requirements of these expanded goals, the Department of Natural Resources has proposed an increase to the collection budget to ensure a ten-year recollection rate at minimum. WGS is looking to achieve ongoing funding to successfully plan and implement the lidar collection strategy described in this document.

Partnerships

Partnerships across the State play an important and critical role in the ability to extend State funding and collect large areas consistently. Funding amounts from these partners are not set or necessarily pre-identified before the planning of each project. The Lidar Advisory Committee will therefore be essential for ensuring that partners are aware of the areas that need data as well as involving the Lidar Advisory Committee with the annual planning process. It is also essential that partners understand the estimated costs and resource requirements for lidar collection to incorporate it into their planning processes. These cost estimates are listed in the Resource Requirements section of this plan.

Grants

Federal grant programs have been essential for Washington State, particularly the USGS 3D Elevation Program (3DEP), which offers federal matching opportunities for lidar collection. WGS plans to continue working with the USGS 3DEP program and apply for funding for the priority areas each biennium. WGS will also likely continue to work with the 3DEP contracting services to maintain consistency and quality across projects. Other state, local, and tribal agencies can also apply to the USGS 3DEP program. Additionally, FEMA grants are often available for flood mapping activities, and WGS has participated in FEMA grant programs to collect key portions of the state.

Contracting

WGS has developed a lidar contract for other Washington partners and agencies to use. This contract has already gone through State procurement processes and has a pre-vetted vendor. WGS provides project management, independent quality assurance, and public dissemination services within this contract. Under the terms of this contract, the data is public domain and published to a public website.

This contract allows groups who have a smaller area of interest and shorter timeframe to meet their requirements outside of a traditional wide-area mapping project and can help the partners work outside of a biennium timeline. This contract also supports consistency between projects and allows for collection in areas that already have lidar data that needs to be refreshed due to environmental change or events, such as wildfires or landslides. WGS expects to continue using this contract mechanism for partner projects and especially bathymetric lidar projects, for which this contract has been a popular option. WGS also expects to expand its use to wide-area recollection projects to help condense the collection and quality assurance timeframes and disseminate the data to the public more quickly.

Resource Requirements

The largest costs associated with lidar collection are for the acquisition and processing of the data. There are costs for the storage and dissemination of the data as well. This section reviews the estimated costs for these resources.

Lidar acquisition and processing costs

Several factors affect the costs for lidar acquisition and processing. Some of the largest contributors to the cost are mobilization of the aerial assets to the location and the amount of area that needs to be covered. While it can seem counterintuitive, the cost of aerial lidar per unit area is reduced as the area to be covered increases in size – with larger, more contiguous area, the efficiency for flight lines and fuel increases. Similarly, terrain type can also affect the acquisition costs, as flying over flat terrain allows for steady, even flight lines. Conversely, steep terrain requires numerous altitude adjustments that increase fuel consumption and time. Project specifications also have an impact, based on "Quality Level", as defined by the USGS Lidar Base Specification. Different quality levels have different parameters for pulse density and flight line overlap, which ultimately affects how the project is flown and the amount of accuracy control is collected by the vendor.

WGS and the lidar vendor negotiated a cost matrix for variable project areas with varying pulse densities to provide partners with an understanding of project cost during the planning phase. For WGS projects, 'QL1' is used to meet the minimum State specifications, however it is noted that some partners may want a higher pulse density to create a better top surface product, and there are some areas of the state where QL2 data is sufficient for some purposes. For wide-area collections, as would be covered in the lidar collection strategy, the 3,000+ square mile category is always reached. The price matrix is presented in Table 2, below. It should also be noted that the terrain and level of difficulty, as well as the products and services required (for example, bathymetry or orthoimagery) may influence the quotes for an individual project. Also listed in the table for comparison is the estimated USGS 3DEP cost for 'medium' terrain for the QL1 and QL2 categories. The 3D Nation study listed these estimated costs based on terrain type, and while Washington State is a mixture of terrain types, the 'medium' category can be assumed in most cases. For collections, it is important to plan for a mixture of terrain, or ecological regions, to distribute costs more evenly. All these cost estimates include acquisition and processing of the data and are subject to change over time.

For those considering a lidar project, contact the WGS for consultation and coordination with statewide activities.

Table 1: Current estimates of lidar acquisition costs, based on square mileage area and pulse density.

Project Area Size (square miles)	QL1: 8 pulses/m^2	20 pulses/m^2	QL2: 4 pulses/m^2 (not recommended by this plan)
1–100	Case by case	Case by case	Case by case
101–200	$606	$775	$381
201–500	$550	$703	$288

501–1500	$385	$492	$260
1501–3000	$360	$460	$232
3000+	$342	$437	$224
USGS 3DEP ‘medium’ terrain difficulty	$433		$220

Storage and Dissemination Costs

Lidar is truly ‘big data’. The volume of the datasets only increases with advancements in sensor technology, higher pulse densities, and spatial resolutions. Older datasets increase in value over time as they contain critical historical information, and therefore should always be retained. The rate of lidar collection also increasing, as most users require refresh rates of 4–5 years over their areas of interest. The complexity and cost of storing and disseminating lidar data has therefore also increased over time.

Currently, WGS stores 171 terabytes (TB) of lidar data, as of October 2023. This is expected to increase by 25—40 TB per year as new data is collected or donated to the State. WGS uses a Network-Attached Storage (NAS) platform to store the core enterprise lidar data, which is backed up weekly. This NAS system has a lifecycle of five years, and as more data volume is added, additional ‘nodes’ are needed to expand capacity. These costs are currently maintained by WGS, and additional ongoing funding is requested in the legislative proposal to meet future storage requirements. While cloud technologies could reduce infrastructure costs over time, primary storage costs are expected to remain high as this data needs to be retained in low-latency storage for retrieval. WGS will work with State and DNR IT to address options for all enterprise-level data in the future.

Disseminating lidar data has traditionally also had high costs and challenges. Lidar data has a number of different products and deliverables, including the data-dense ‘point-cloud’, which is the primary lidar product. At minimum, WGS disseminates the point cloud, digital elevation models (DEMs), hillshade products for visualization, and metadata products through the Washington Lidar Portal, with more products expected in the future. The Lidar Portal is currently maintained on cloud infrastructure, and the largest costs are maintaining the infrastructure and ‘egress’ costs, or the cost each interaction incurs as users browse and download the data. As data volumes increase, WGS has observed that egress costs also increase, and budgeting for these costs is challenging. WGS is working with IT staff to migrate the Lidar Portal to state data center infrastructure so that resources will be maintained by enterprise best practices, and egress costs will become more predictable. Should enterprise solutions move to the cloud, the Lidar Portal will be migrated and maintained there by broader DNR workflows and IT enterprise management practices.

Staff

WGS has two permanent staff to manage lidar collections, policies, standards, and data quality. WGS plans to add a third staff position to expand support for newly acquired data and the lidar portal migration. An IT Division staff position was also added to support the Lidar Portal infrastructure and dissemination solutions.

Technical Specifications and Standards

Unless otherwise specified by funding sources or acquisition partners, the most current version of the USGS Lidar Base Specification[2] will be used to define the baseline parameters of new lidar projects. Some additional requirements WGS specifies are listed below:

- For all new acquisitions, the aggregate first return pulse density will be >8.0 points per square meter or higher. Overall, the equivalent Quality Level for all Washington State acquisitions is QL1 or higher.
- By default, survey conditions will be conducted during the leaf-off period for the survey area. This requirement may be relaxed for higher elevation survey areas where the number of deciduous trees is limited, in areas where overall vegetation is limited, or when snow and terrain conditions provide a challenging environment that narrows the collection timeframe considerably.
- The collection will be designed such that there is at least 50 percent sidelap and 100 percent double coverage for each flightline.
- In addition to a bare earth surface model, a first return surface model is required to be delivered as well, generated from the highest collected return (disregarding noise) for each raster cell.
- Additionally, the data is required to be delivered in NAVD88, NAD83- HARN (or CORS96 labeled as HARN for GIS purposes) Washington State Plane South. This will be the standard until additional options for the state are made available through the National Geodetic System datum upgrade.
- Hydroflattening (setting each inland water body at a single consistent elevation, and systematically “stepping” rivers downstream) is required to comply with the USGS Lidar Base Specifications, however partners may choose not to use hydroflattening if their use case requires other hydrology treatment or to leave water in its raw state.

While the WGS collections closely adheres to and reference the most current USGS Lidar Base Specifications (LBS) document, there are a few key differences. The most notable exception is the baseline Quality Level. For Washington State, quality level 1 (QL1) data with a minimum aggregate density of 8 pulses per square meter is required. Without this level of density, the bare earth under even

[2] USGS, 2023, Lidar Base Specification Rev A [accessed October 23, 2023, https://www.usgs.gov/media/files/lidar-base-specification-2023-rev-a]

moderate vegetation or terrain cannot be accurately characterized. For other applications, such as urban development and resource planning, a QL1 lidar dataset is needed as a baseline for future work and serves a much wider range of applications. Previous versions of the USGS LBS have held QL2 to be the standard for mapping acquisitions, however it should be noted that future updates to the USGS Lidar Base Specification will likely update the standard to QL1.

The current version of the USGS Lidar Base Specification may also be used for survey control standards, vertical and horizontal accuracy standards, metadata standards, tiling schemes and naming conventions.

Lidar Products and Deliverables

At minimum, the following products and deliverables should be available for all new acquisitions.

- All-return classified point cloud—This product is the primary lidar data, needed by users who want to generate their own surfaces, look at vegetation structure, examine infrastructure, or conduct more in-depth analyses. Modern formats are either LAS or LAZ (compressed), yet some historical data may still be in text file or ascii formats.

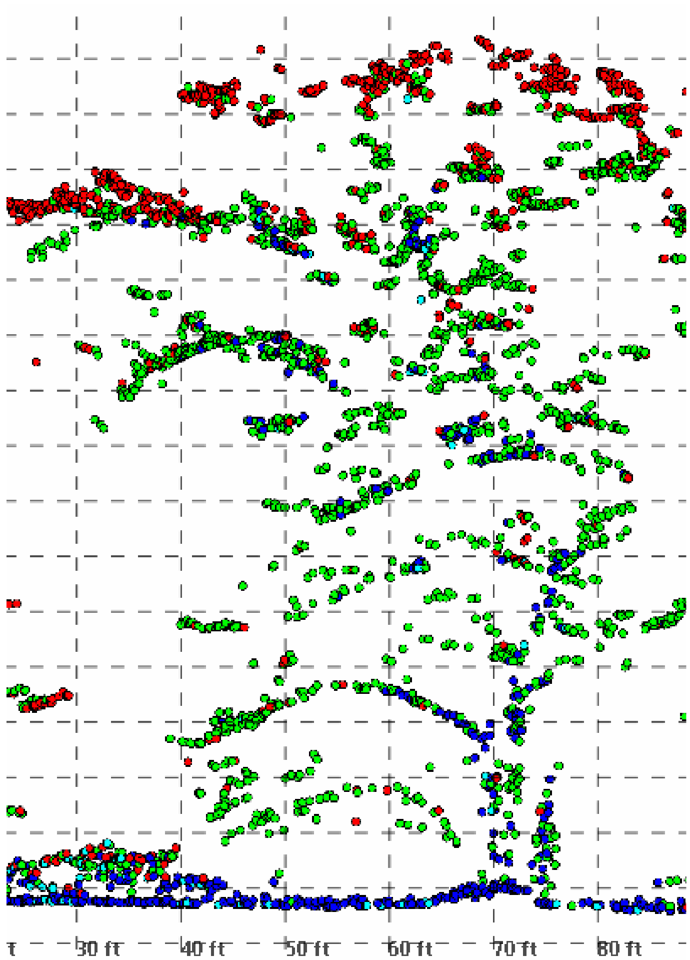


Figure 5. Whereas a raster surface only captures one aspect of the data (lowest returns, first returns) the point cloud represents all returns and can be very useful for understanding the 3D nature of objects. Here the whole structure of a tree is represented.

- Bare earth surface model (Digital Elevation Model (DEM) or Digital Terrain Model (DTM))—This is a derived raster dataset that filters out all points other than verified ground points and is used for slope stability studies, engineering, and modeling studies. File formats are typically geotiff, Esri grid, or imagine raster files. For WGS products, the DTM will also be hydroflattend, per the USGS Lidar Base Specification document.

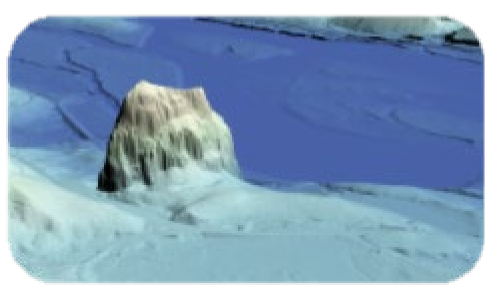


Figure 6: Example of a bare earth DEM, vegetation and structures are removed

- First return surface model (Digital Surface Model or DSM)—This product represents the highest collected return from each cell (disregarding noise), delivered in a raster format such as geotiff, Esri grid or imagine file. This product deviates from the USGS Lidar Base Specification, but having a standardized first return surface model has proved useful for forestry, habitat, and urban development applications.

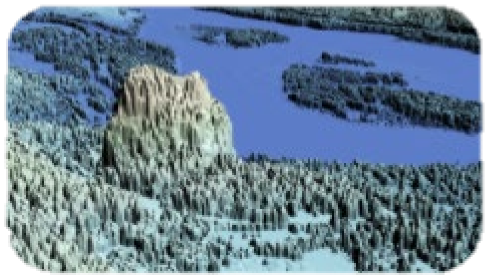


Figure 13: Example of a first return DEM which includes vegetation and man-made structures

- Intensity images, a derived raster that indicates the strength of the return to the instrument—These are generally delivered at the same resolution as the DTM and DSM products, and in the same file format. This product can be useful for understanding the hydrology at the time of collection, or distinguishing features such as buildings and roads, as these structures often have stronger returns than ground or trees.

Figure 14: Example of a lidar intensity image, which represents the strength of the returned measurement to the lidar system.

- Survey report—The survey report includes information on the project itself, such as location, dates of data collection, a description of the lidar acquisition and ground survey techniques and results, as well as an accuracy assessment. These reports are very useful for anyone needing to understand how the collection was conducted, how accurate the data is, and what the best use of the data is.
- Ground control points and calibration points—These points help people understand how accuracy was measured for the dataset and allows them to evaluate these points themselves to understand the accuracy for their own needs. These products also help in the QA process.
- Recorded aircraft trajectory data, or flight lines—These data record the aircraft position and altitude with attributes for the date and time of each flightline. They are used when the exact

time of collection is needed (for example, comparative vegetation studies during a particular season, or looking at low tide data).
- Formal metadata—This product is provided in xml format, as described by the USGS Lidar Base Specification.

Additional products may be required based on the project. Examples include: orthoimagery, specific quality assurance rasters, hydroflattened surface models and associated breaklines, bathymetric surface models, and bathymetric coverage vector data. For historical projects (typically before 2015 or so), the availability of some of these products may be limited.

Plan Maintenance and Data Management

Maintenance of the Collection Strategy

The Washington State Lidar Plan reflects a collection strategy and long-term goals to reflect changes in technology and in the community. It is anticipated that this strategy will be reviewed every two years Updates that would prompt revisions to this plan include the development of a formal bathymetric lidar acquisition strategy, updates to data products, deliverables, or formats, or inclusions of additional elevation technologies.

Annual data acquisition plans will be reviewed each spring by the Lidar Advisory Committee. The final acquisition plan for that year will be posted digitally on the Washington Geological Survey Lidar Program website.

Data Management Plan

This section reviews standard data formats expected for lidar data, as well as storage estimates and the current distribution methods.

Data Formats and Sizes

Lidar data and derivative datasets are typically comprised of:

- point cloud data, generally in a LAS or compressed LAZ format
- raster products for digital elevation models and intensity images
- vector products for ground control, breaklines, and flight data
- xml metadata
- text formats for survey reports

Additional information on data formats can be found in the most current version of the USGS Lidar Base Specification. Overall, lidar data is large—by using recent 3DEP lidar projects to gauge the modern size and density of data for the QL1 data, it is estimated that the storage needed for a single, consistent, coverage of Washington State is ~275 TB. It is expected that an additional 25–40 TB of data will be acquired annually, either through collections or donated projects. This is in addition to historical datasets already available.

Data Storage, Backup, and Archival

Lidar data is currently stored in NAS storage at the state data center. To maintain the enterprise lidar datasets, it is expected that this system or a comparable storage strategy will need to be replaced every five years, with additional storage added every one to two years to support new data acquisitions. The Department's Information Technology Division maintains infrastructure for enterprise-level data, as well as data backup, restoration, and disaster recovery response. The lidar data is backed up weekly, and copies are maintained in a secure off-site location. Additionally, all original lidar data, as delivered or received, is archived by an off-site cloud provider.

Data Sharing and Distribution

All lidar data collected by WGS is publicly available, along with the public datasets that are donated to WGS by other agencies and organizations. Currently, the Washington Lidar Portal (lidarportal.dnr.wa.gov) is the primary method of data distribution. Point cloud data, digital elevation model quadrangle tiles, hillshade quadrangle tiles, and survey reports are available in LAZ, TIFF, or PDF formats. Additional data may be available upon request, such as breaklines, intensity images, or ground control points, depending upon the project. The Washington Lidar Portal is maintained by WGS and DNR ITD staff and is anticipated to be updated every five years to include updates in user interface design, APIs, download or streaming technologies, and additional tools that will enhance the user experience.

Future Challenges

As this plan is reviewed biennially, challenges will be discussed with the Lidar Advisory Committee to identify solutions. Identified here are the following challenges facing statewide lidar data collection:

- **Establishment of ongoing funding**. The strategy described here is largely based on the assumption that ongoing funding will be available from the State to ensure that a recollection program of ten years or less can be established. If ongoing funding is not available, funding sources may be unpredictable from year to year.
- **Tribal Nations**. There are several sovereign tribal nations in Washington State. Many are enthusiastic about lidar data and collection opportunities and have worked alongside the State to collect data over their areas of interest. Some tribal nations may be less enthusiastic about public lidar data collection over their lands, and this plan will need to take those concerns into account.
- **Changing data formats**. The National Geodetic Survey is in the process of converting the nation to datum 2022, which will change the national horizontal datum, vertical datum, and geoid model. Another data change is the USGS change of archival file format from .las to .laz, a compressed version of the point cloud data. While this will save on storage, most users will need to decompress the data in order to use it with standard GIS software.
- **Communicating value to executive leadership**. Many of our partners at the Lidar Advisory Committee meeting expressed the need to create materials regarding the value of lidar, the benefits, and the return on investment for their leadership.

- **Making the most of the data**. Lidar data is extremely valuable for analyses that affect safety and habitats. However, training on how to use lidar to its fullest potential, creating derived products for users and developing techniques to facilitate sharing (for example, rest services for common features) will only increase its value.
- **New technologies**. There may be future opportunities to expand this plan to include other lidar innovations or technologies.

Additional References

There are numerous additional references that can expand on topics related to lidar, lidar data collection, and applications. Included below is a selection of additional references.

- **Washington Lidar Program**: lidar program website with resources for planned collection areas, current lidar coverage extents and boundaries, and information about lidar and its uses:
  https://www.dnr.wa.gov/lidar
- **Washington State Lidar Portal**: Download access to lidar data and products:
  http://lidarportal.dnr.wa.gov/
- **Washington State Bare Earth Story Map**: explains lidar and showcases the use of lidar data for Washington geology:
  https://wadnr.maps.arcgis.com/apps/Cascade/index.html?appid=36b4887370d141fcbb35392f996c82d9
- **Washington State Lidar Plan digital guide**: online summary for this plan:
  https://TBD

- **USGS Resources:**
  - **USGS National Map (USGS NM)**: https://apps.nationalmap.gov/viewer/
  - **USGS NM 3DEP Viewer:** https://apps.nationalmap.gov/3depdem/
  - **USGS 3DEP Lidar Explorer**: https://apps.nationalmap.gov/lidar-explorer/#/

- **NOAA Resources:**
  - **NOAA US Federal Mapping Coordination Map**: provides outlines for federal areas of interest for lidar data collection.
    https://www.seasketch.org/#projecthomepage/5272840f6ec5f42d210016e4/about
  - **United States Interagency Elevation Inventory**:
    https://coast.noaa.gov/inventory/

Appendix A

The following agencies and organizations have participated in the Lidar Advisory Committee and present feedback on the lidar strategy and annual collection plans.

State Agencies	**Federal Agencies**
Washington State Department of Natural Resources	U.S. Bureau of Reclamation (USBR)
Washington State Department of Ecology	U.S. Geological Survey (USGS)
Washington State Department of Fish and Wildlife	U.S. Forest Service (USFS)
Washington State Department of Transportation	Natural Resources Conservation Service (NRCS)
Washington State Recreation and Conservation Office	Federal Emergency Management Agency (FEMA)
	National Oceanographic and Atmospheric Administration (NOAA)
Counties	**Tribes**
Island County	Yakama Nation
Kitsap County	Quinault Indian Nation
King County	Tulalip Tribes
Chelan County	Spokane Tribe of Indians
Pierce County	Puyallup Tribe
Benton County	Suquamish Tribe
Columbia County	Muckleshoot Indian Tribe
Pend Oreille County	Lummi Nation
Stevens County	Port Gamble S’Klallam Tribe
Ferry County	Lower Elwha Klallam Tribe
Spokane County	**Other Organizations**
Thurston County	Northwest Indian Fisheries Commission
Douglas County	Skagit River System Cooperative
Asotin County	Yakima Basin Fish and Wildlife Recovery Board
Lewis County	Puget Sound Partnership
Kittitas County	Cascadia Conservation District
Whatcom County	A Salish Alliance
San Juan County	Upper Columbia River Salmon Recovery Board
Snohomish County	Cooperative Monitoring Evaluation and Research
Yakima County	
Cities	
City of Seattle	

City of Longview	
City of Marysville	
City of Bellevue	
City of Federal Way	
City of Everett	
City of Spokane Valley	