Guidance for Flood Risk Analysis and Mapping

Elevation

November 2024

FEMA

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Requirements for the FEMA Risk Mapping, Assessment, and Planning (Risk MAP) Program are specified separately by statute, regulation, or FEMA policy (primarily the Standards for Flood Risk Analysis and Mapping). This document provides guidance to support the requirements and recommends approaches for effective and efficient implementation. Alternate approaches that comply with all requirements are acceptable.

For more information, please visit the FEMA Guidelines and Standards for Flood Risk Analysis and Mapping webpage (https://www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping). Copies of the Standards for Flood Risk Analysis and Mapping policy, related guidance, technical references, and other information about the guidelines and standards development process are all available here. You can also search directly by document title at https://www.fema.gov/resource-document-library.

Table of Revisions

The following summary of changes details revisions to this document subsequent to its most recent version in November 2023.

Affected Section or Subsection	Date	Description
1, 3.1	Nov. 2024	Updated discussion of 3DEP lidar coverage for project planning.

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1. Introduction

This elevation guidance document retires Appendix A of the Guidelines and Specifications for Flood Hazard Mapping Partners (Guidelines) and Procedure Memorandum 61 – Standards for Lidar and Other High Quality Digital Topography while modernizing the guidance to align with the U.S. Geological Survey (USGS) Lidar Base Specification (2022 rev. A or more current), American Society for Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0 – November 2014 or more current), and ASPRS LAS Specification (Version 1.4 – R13, 15 July 2013 or more current).

FEMA has standardized on Quality Level 2 data as defined in the USGS Lidar Base Specification for new light detection and ranging (lidar) acquisition consistent with the goals of the three-dimensional (3D) Elevation Program (3DEP). 3DEP is a multi-agency federal, state, and local effort to systematically collect enhanced elevation data in the form of high-quality lidar data over the conterminous United States, Hawaii, and the U.S. territories. Quality Level 2 was selected as the baseline specification for 3DEP because it provided the optimum balance of benefits and affordability. The second generation of coverage for 3DEP is being planned as a combination of Quality Level 2 and Quality Level 1 data.

This document provides basic information on elevation data terminology, data formats for datasets used in the Risk MAP program, references for accuracy and other lidar topics, as well as guides for procurement of either leveraged or newly acquired elevation data.

2. Elevation Data Basics

This section describes the basic elevation terminology and concepts. The content is not meant to be a thorough discussion on elevation data; rather, it is meant to provide basic information to the end user so they have an understanding of the terrain data used to complete flood insurance study datasets required by the Risk MAP program.

2.1. Digital Elevation Data

Digital Elevation Data encompass many data types. This section is not meant to limit method selection but to describe those that are typically acquired for the purpose of hydrologic and hydraulic analysis, floodplain delineation, and Risk MAP product development. For additional definitions or data type descriptions, please refer to the USGS Lidar Base Specification glossary.

2.1.1. LIDAR

Lidar is defined as a laser system that acquires x, y, and z coordinates of terrain and terrain features that are either human-made or naturally occurring. Lidar systems consist of a Global Positioning System (GPS) with attendant GPS base stations, an Inertial Measurement Unit (IMU), and a light-emitting scanning laser. The lidar system can be mounted on a number of platforms, including satellites, aircraft, boats, automobiles or trucks, or stationary tripods. Typical lidar collection for the purpose of establishing a terrain surface for floodplain mapping involves fixed-wing, aircraft-mounted laser scanning sensors. Further discussion in this document is specific to this collection platform.

The system measures ranges from the scanning laser to terrain surfaces within a scan width beneath the aircraft. Measuring the time it takes for the emitted light (lidar return) to reach the earth's surface (or other feature being measured) and reflect to the onboard lidar detector determines the range to the ground. Scan widths will vary, depending on mission purpose, weather conditions, desired point density and spacing, and other factors.

Two important factors in the lidar system mission planning are the pulse spacing of the randomly spaced lidar points and the point spacing of the uniformly spaced Digital Elevation Model (DEM) points derived from the randomly spaced lidar returns. Current specifications typically require sufficiently dense nominal pulse spacing to support floodplain mapping, so the density or resolution of the data is not normally a critical factor. However, issues may arise where very dense vegetation prevents most measurements from reaching the ground, resulting in actual measurement density well below the nominal pulse spacing.

Lidar missions can be flown without regard to sun angle and may take place at night if conditions otherwise allow. Lidar system tolerance for inclement weather conditions (e.g., high winds, wet snow, rain, fog, high humidity, low cloud cover) generally is higher than that of photogrammetric methods. However, such conditions have been known to degrade the accuracy of the laser return data and may pose a safety risk in rugged terrain.

In some instances, shallow water and near-shore coastal surveys can be accomplished using airborne lidar bathymetric systems equipped with lasers operating in portions of the light spectrum that allow transmission through water. Detailed information about lidar, including nomenclature, definitions, and requirements, can be found in the USGS Lidar Base Specification and ASPRS Positional Accuracy Standards for Digital Geospatial Data.

A lidar deliverable usually comprises several different data components, including the raw and classified data that are a direct result of the data capture and the derived products.

Next-generation lidar sensors, commonly called "photon-counting" or "Geiger-mode" lidar sensors, are in development and beginning to be offered commercially. The output from these sensors is somewhat different than the conventional linear-mode laser scanning systems used commercially over the past 15 years, though if they perform as advertised, they will be useful and cost-effective for flood mapping. Data from these systems may be used for FEMA flood mapping projects if they can meet the elevation data requirements in the Risk MAP standards, but careful testing should be implemented to verify the data are suitable.

2.1.2. LAS FILES

Both Raw and Classified Point Cloud data are stored in Lidar Aerial Survey (LAS) files. This file format has become the industry standard for storing lidar and should generally be used for all projects (see ASPRS LAS Specification).

Raw Point Cloud

During lidar acquisition, sensors collect irregularly spaced mass points via a pulsed laser range finder. The data are a collection of range measurements and sensor orientation parameters. The initial processing and analysis of laser data to raw point clouds (sometimes known as calibrated point clouds) in some specified tile format is commonly referred to as preliminary processing. When the processing is complete, the lidar data will be set to ASPRS LAS Class 1 (unclassified). This raw point cloud typically includes discrete first, last, and intermediate returns for each laser pulse that indicate the location of objects in three-dimensional space. In addition to spatial information, the lidar point cloud includes intensity data that can be used to create an image resembling a black-and-white photo of the area collected. Building locations, intensity images, and forest canopies are among the many uses for raw point cloud data.

Fully Classified Point Cloud

The final processing and classification of lidar data to the required ASPRS LAS classes, per project specifications, is typically referred to as Post-Processing. The lidar raw point cloud data are processed through a series of semi-automated algorithms to filter and organize points into groups. These point groups are visually inspected and refined to separate the points into specific classifications such as buildings, water, vegetation, or bare earth. The final dataset is known as a fully classified point cloud. The dataset may be parsed into various LAS Class datasets, such as LAS Class 2 or the bare earth dataset.

Bare Earth

Bare Earth is a lidar classification that is free from vegetation, buildings, and other human-made structures. Bare Earth contains only the ground topography and is stored in classification 2 within an LAS file. The Bare Earth point classification is used for creating digital topographic surfaces that are the basis for hydraulic analysis and floodplain mapping.

2.1.3. BREAKLINE

A breakline is a linear (sometimes referred to as a vector) feature that describes a change in the smoothness or continuity of a topographic surface. Breaklines are often embedded in Esri Terrain or Triangular Irregular Network (TIN) datasets to improve the model of the earth's surface. Breaklines of wide streams (greater than 100 feet) and waterbodies (greater than 2 acres) are required to produce the Hydrologically Flattened DEM in the USGS Lidar Base Specification. Breaklines are generally derived from the lidar data, but might also be collected from orthophotography.

2.1.4. LIDAR PRODUCTS

Digital Elevation Model

The digital representation of continuous elevation values at regularly spaced or gridded intervals in x and y directions is known as a DEM. DEMs are typically derived from TINs, which are created using

Bare Earth classified lidar. Because of the uniform point spacing, DEMs can "jump over" breaklines without identifying ditches, stream centerlines, steep banks, and other similar features. DEMs are simple data models, easy to store, and suitable for automated hydrologic and hydraulic analyses and modeling where breakline information is unimportant or introduced in another manner (such as streamlines for hydraulic modeling). DEMs are commonly used in hydraulic modeling and floodplain delineation.

Hydrologically (Hydro) Flattened Digital Elevation Data

The hydro-flattened DEM is valuable to the hydraulic analysis when there are wide streams and many ponds or lakes. By including breaklines, this DEM provides a consistent elevation for the water surface for lakes and bank-to-bank for rivers. Base Flood Elevations (BFEs) produced by hydraulic analysis will thus be constant for lake surfaces and have a smooth progression for rivers. This approach improves the throughput for the analysis as less time is required to “clean up” the floodplains. Some caution should be used with these processed DEMs because the elevation values for the water surface are artificially generated to create a cartographically pleasing surface. Small islands, large boulders, shoals and other features within the channel banks may be smoothed out of the original data.

Where the hydro-flattened DEM does not represent the stream channel effectively, the user should consider the classified point cloud, potentially in combination with the breaklines for hydraulic modeling.

Contours

A contour is a representative line of equal elevation on a surface. It is an imaginary line on the ground, all points of which are at the same elevation above or below a specified vertical datum. Contours are created from the Bare Earth data, or from the DEM. These contours can be used to produce or review floodplain delineations manually. A series of algorithms creates and smooths cartographic contours to produce smooth map quality contours.

2.2. Data Formats

While the preceding section lists a wide variety of formats for the listed datasets, as described in the USGS Lidar Base Specification, the acceptable formats for FEMA deliverables are prescribed in the Data Capture Technical Reference.

2.3. Tiling Scheme

The USGS Lidar Base Specification discusses tiling scheme requirements. Tile sizes should take into consideration the end-user requirements. All stakeholders and collection partners must make the final determination of a tiling scheme before collection of the data. As noted by both the USGS document and the Data Capture Guidance – Workflow Details, a title index file must accompany tiled data.

2.4. Accuracy

Accuracy is defined as the closeness of an estimated value (for example, measured or computed) to a standard or accepted (true) value of a particular quantity. The following sections describe accuracy, as it relates to the requirements for lidar datasets, and a generalized description of the testing requirements for these datasets. The USGS Lidar Base Specification has additional accuracy requirements and information.

2.4.1. GEOSPATIAL ACCURACY STANDARDS

A geospatial accuracy standard is a common accuracy testing and reporting methodology that facilitates sharing and interoperability of geospatial data. Published in 1998, the National Standard for Spatial Data Accuracy (NSSDA) is the Federal Geographic Data Committee (FGDC) standard most relevant to digital elevation data.

The USGS Lidar Base Specification requires vertical accuracies based on the ASPRS Positional Accuracy Standards for Digital Geospatial Data, which characterizes lidar accuracy in terms of Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA). This system separates the overall system and measurement uncertainties observed in non-vegetated areas from the additional uncertainties introduced when trying to distinguish measurements of the bare earth from measurements of vegetation. Please see the referenced publications for further discussion on these terms and the calculations required to determine their values for a particular dataset.

The USGS vertical accuracy specifications apply to both the lidar (LAS) datasets as well as the derivative DEMs for newly acquired data. Construction of the DEM requires interpolation, resolution changes, post-spacing decisions, and interim surfaces. These steps may potentially introduce additional error; thus, the vertical accuracy of the DEM is not expected to be the same as the LAS dataset, and in fact will tend to be slightly worse. Please see USGS Lidar Base Specification for further information and description of these requirements.

Standard ID (SID) 40 requires new elevation data purchased by FEMA to comply with the USGS Lidar Base Specification at a minimum. To comply with SID 43, existing topographic data leveraged by FEMA must have documentation that it meets the vertical accuracy requirements described in Table 1.

Table 1: Vertical Accuracy Requirements Based on Flood Risk and Terrain Slope Within the Floodplain Being Mapped

Level of Flood Risk	Typical Slopes	Specification Level	Vertical Accuracy: (FVA or NVA*) / (CVA or VVA**)	Lidar Nominal Pulse Spacing (NPS)
High (Deciles 1,2,3)	Flattest	Highest	24.5 cm / 36.3 cm	≤ 2 meters
High (Deciles 1,2,3)	Rolling or Hilly	High	49.0 cm / 72.6 cm	≤ 2 meters
High (Deciles 2,3,4,5)	Hilly	Medium	98.0 cm / 145 cm	≤ 3.5 meters
Medium (Deciles 3,4,5,6,7)	Flattest	High	49.0 cm / 72.6 cm	≤ 2 meters
Medium (Deciles 3,4,5,6,7)	Rolling	Medium	98.0 cm / 145 cm	≤ 3.5 meters
Medium (Deciles 3,4,5,6,7)	Hilly	Low	147 cm / 218 cm	≤ 5 meters
Low (Deciles 7,8,9,10)	All	Low	147 cm / 218 cm	≤ 5 meters

*Fundamental Vertical Accuracy (FVA) and NVA are reported at the 95 percent Confidence Level.
**Consolidated Vertical Accuracy (CVA) and VVA are reported at the 95th Percentile.

Prior to the USGS Lidar Base Specification, most elevation data projects used a similar accuracy framework published by the National Digital Elevation Program (NDEP) in its Guidelines for Digital Elevation Data and the ASPRS Guidelines: Vertical Accuracy Reporting for Lidar Data. Both were published in 2004 and use the terms: Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). CVA is a value that blends the FVA and SVA measurements.

Since much of the leverage data currently available follows the older FVA, SVA, and CVA requirements, Table 2 provides a crosswalk of these terms. Table 2 also provides a crosswalk of the testing requirements. Because FVA is so similar to NVA, and SVA is so similar to VVA, FEMA uses the same minimum accuracy values in both systems.

Table 2: Land Cover Classes

Class Number	Land Cover Class or Description	Previous Reporting Group	Current Reporting Group
1	Clear or open, bare earth, low grass; for example, sand, rock, dirt, plowed fields, lawns, golf courses	FVA	NVA
2	Urban areas; for example, tall, dense human-made structures	SVA	NVA
3	Tall grass, tall weeds, and crops; for example, hay, corn, and wheat fields	SVA	VVA
4	Brush lands and short trees; for example, chaparrals, mesquite	SVA	VVA
5	Forested areas, fully covered by trees; for example, hardwoods, conifers, mixed forests	SVA	VVA
6	Sawgrass	n/a	n/a
7	Mangrove and swamps	n/a	n/a

* Terminology: Fundamental Vertical Accuracy (FVA), Non-vegetated Vertical Accuracy (NVA), Supplemental Vertical Accuracy (SVA), Vegetated Vertical Accuracy (VVA), Not applicable (n/a)

2.4.2. ACCURACY REPORTING

Dataset accuracy must be reported in the accompanying metadata records. The ASPRS Positional Accuracy Standards for Digital Geospatial Data provides accuracy statements.

2.4.3. LOW CONFIDENCE AREAS

When the VVA testing fails, low confidence areas will be developed. These areas are poorly defined by the lidar points reaching the earth's surface. Areas of impenetrable vegetation such as cornfields, dense evergreen forest, or mangroves may exhibit this characteristic. Specific guidelines for development of the low-confidence polygon and the reporting requirements are found in the ASPRS Positional Accuracy Standards for Digital Geospatial Data.

2.5. Pulse/Point Spacing

The density of pulses (or points) in a lidar collection affects the functional accuracy of a dataset since interpolation is required between pulses and features between pulses can be missed. The density is typically measured in two ways. The first measurement is commonly referred to as Nominal Pulse Spacing or Nominal Pulse Density. This measurement refers to the expected density of pulses based on the design of the lidar acquisition project. Lidar datasets are irregularly spaced; hence, these measurements calculate the average spacing. Modern lidar sensors have become capable of creating high collection densities with nominal pulse spacing of less than 1 meter. The tighter the spacing, the more definition of the earth's surface is possible.

Typically, the point spacing of the DEM is also specified. The Nominal Pulse Spacing must be sufficiently dense to support the target DEM point spacing. DEM datasets are derived and thus are regularly spaced points in a grid pattern. DEM point spacing is also referred to as “post spacing” or “cell size.” Refer to the USGS Lidar Base Specification for further discussion on this topic.

USGS Lidar Base Specification provides a description of the required pulse density and the DEM cell size to satisfy various Quality Level definitions.

2.6. Field Survey

2.6.1. GROUND CONTROL

Ground control points are surveyed under rigorous standards to provide the lidar processing team with known elevations at known locations. The purpose for the ground control points is twofold. First, they provide the processing team the ability to conduct a vertical accuracy test on the dataset prior to conducting the vertical accuracy test described in the checkpoint section below. This preliminary testing may lead to the second purpose of the ground control, that being its use in evaluation of the lidar data to ensure the data properly “ties” to the actual ground elevations. If a significant difference is noted throughout the dataset, the ground control may be used to determine a block adjustment to more accurately “tie” the data to the ground elevations. A discussion on the accuracy of the ground control may be found in the ASPRS Positional Accuracy Standards for Digital Geospatial Data.

2.6.2. CHECKPOINTS

Vertical accuracy of elevation datasets requires statistical analysis of the differences (errors) between the dataset and known elevations at specific locations. A field survey conducted under rigorous standards provides these known test elevations. When possible, a field survey should be conducted by a third-party entity, such that the points are held until processing is complete and a “blind” test can be conducted. The blind test provides the client confidence that the dataset meets or exceeds the requirements set forth at contract signing. Further description of the checkpoint requirements may be found in the ASPRS Positional Accuracy Standards for Digital Geospatial Data and the USGS Lidar Base Specification.

3. Obtaining Elevation Data for Risk MAP

3.1. Acquisition Planning for Lidar Data

Whenever possible, lidar should be planned and acquired so that it is available before commencing Discovery. This approach provides the biggest benefit from the lidar and allows the maximum use of streamlined analyses for the project. SID 29 requires all projects to identify or develop data during Discovery that approximates the floodplain and flood elevation results that are likely to result from a Flood Risk Project. Discovery Guidance describes how Base Level Engineering (BLE) data can be used to support engagement and communication activities. This approach is likely to produce efficiencies where the BLE results can be shared as advisory data and/or reused on the regulatory maps with additional refinement as needed. This approach requires FEMA to be much more proactive in acquisition planning for lidar, ahead of any future Flood Risk Projects.

FEMA is committed to supporting the USGS 3DEP as a core strategy for partnering on elevation data collections. Collaboration between FEMA and other federal and state agencies supports high quality, multiuse lidar coverage across the nation. FEMA's Risk MAP program can leverage funding to help make this coverage possible. Participation in 3DEP allows FEMA to be more proactive in its lidar collection and to benefits from partnerships.

The critical step to successfully intersecting the 3DEP and Risk MAP Programs is acquisition planning. Leveraging tools like the Coordinated Needs Management Strategy (CNMS) and ensuring that our Cooperating Technical Partners (CTPs) maintain their business plans can help inform and drive FEMA's decisions on where lidar should be purchased. All areas of a planned project that contain unmapped stream miles or unverified stream miles to be addressed in a project should have suitable lidar available prior to Discovery. To ensure that the lidar purchased is aligned with Risk MAP priorities, regions need to have a multi-year plan for future work.

When planning for lidar acquisition, several things should be considered when developing areas of interest. Based on current standards for Risk MAP project development, lidar acquisition boundaries should normally align to the watershed boundaries for the Flood Risk Project, unless there are existing elevation data that meets FEMA's standards or there are substantial contiguous portions of the watershed that are unlikely to require any flood hazard analysis. It is important to consider, however, gaps that may be created either between the watershed and previously existing lidar, counties that are being split between lidar coverage, or irregular shapes that will be inefficient to collect and will require future complex collection areas to fill in adjacent unmapped areas. When planning the acquisition area, FEMA regional offices should consider the current Risk MAP needs, the efficiency of collecting the planned project, and the efficiency of a future project required to collect the unmapped areas adjacent to the FEMA project. FEMA should normally collect large, regularly shaped, contiguous blocks of new elevation data avoiding slivers and gaps with adjacent existing elevation data that will be inefficient to collect in the future.

Led by the National Oceanic and Atmospheric Administration (NOAA) and the USGS, the agencies participating in 3DEP have developed the U.S. Interagency Elevation Inventory. This inventory is the best source for determining if elevation data already exists for a location. In addition to this inventory of existing data, federal agencies working on elevation mapping have collaborated to build a website, the U.S. Federal Mapping Coordination Viewer, where 3DEP participants or partners, including FEMA and other groups, share elevation data needs and plans. While no inventory is perfect, the absence of adequate elevation data in either of these inventories[1] is a reliable indication that new elevation

[1] The U.S. Interagency Elevation Inventory is hosted by NOAA's Digital Coast (https://coast.noaa.gov/digitalcoast/). The U.S. Federal Mapping Coordination site is hosted at the following link, but it is expected to migrate to the Federal GeoPlatform in the future (https://www.seasketch.org/#projecthomepage/5272840f6ec5f42d210016e4/layers).

data will likely be required for a Flood Risk Project. FEMA should also coordinate with state and key local partners to confirm the need for updated elevation data.

Once the areas of interest have been developed, the areas need to be uploaded to the Project Planning and Purchasing Portal (P4) Tool (for additional guidance on uploading data to P4, please refer to the P4 Tool's Best Practices Guide). This step is critical because the planned and potential lidar projects in the P4 tool will be published to the U.S. Federal Mapping Coordination Viewer. The viewer allows all interested stakeholders to view areas of interest provided by other federal, state, and local agencies and shows where they intersect. This knowledge can help the FEMA regions start conversations with other agencies about possible collaboration and partnerships when it comes to the acquisition of lidar. It can also make partners aware of FEMA's plan to avoid overlaps.

There may be certain situations where the use of elevation data that does not meet SID 43 is acceptable for hydrologic analysis or Flood Risk Products if lidar data does not exist. While this solution is good for specific situations, the FEMA Project Officer should consider the potential impacts on the perception of the overall project data quality. Care should be exercised to avoid using lower accuracy DEMs in areas where the data precision will result in negative perceptions of Risk MAP products overall and should generally not be used for advisory flood zone information.

3.2. New Acquisition of Elevation Data

3.2.1. WHAT STANDARDS APPLY?

All newly acquired data must comply with SIDs 40, 41, 42, 44, 45, 46, 49, 158, and 547.

3.2.2. WHAT ARE THE COST FACTORS?

If the decision is made to purchase lidar, several factors must be considered as they can affect costs.

Climate Constraints

Collection requirements as documented in the USGS Lidar Base Specification dictate that there be no clouds or fog between the aircraft and the ground, that the ground be free from extensive flooding or inundation as well as snow cover, and that data collection occur during leaf-off conditions if possible. These condition requirements drive scheduling constraints, which then factor into the associated costs. For example, an area may be subject to night and/or early morning fog layers. This restricts collection to afternoon hours and may require aircraft and flight crews to be deployed to the location for multiple days. Snowfall, flooding conditions, or forest fires may delay collection for an indefinite period. If collection had started but was not completed, additional costs for ferry time, aircraft fuel, and lodging/per diem costs for the crew may be incurred. If an area has a propensity for these issues, the vendor will typically build in additional costs to cover the likelihood of a prolonged collection period.

Geography Constraints

In many instances, collection in remote areas requires additional time and cost. The vendor may need to get the crew and aircraft to a location distant from their base of operation. Ferry time, aircraft fuel costs, lodging for the flight crew, and sometimes additional tie-down expenses may add additional costs to the acquisition. If the remote area is also subject to prolonged adverse weather events, additional down-time costs for the flight crew may need to be considered.

Shape and Size of the Collection Polygon

Following the USGS Lidar Base Specification, all collection areas must be buffered by 100 meters such that the data remains consistent to the defined collection area.

The shape of the collection area is important to the development of the flightline layout. All flightlines must be straight lines; thus, curved or other irregular collection area shapes require additional flightlines to cover the area. Additional flightlines mean additional flight time for turns and overlap.

Terrain Constraints

Similar to the shape of the collection polygon, terrain constraints may introduce the requirement for additional flightlines. Collection in narrow mountain valleys introduces constraints in the ability to fly in straight lines as well as in the ability to safely gain altitude and turn the aircraft to collect the next flightline. Flightlines may need to be very short with a more angular overlapping pattern. These areas also must be flown under ideal weather conditions for safety considerations.

Collection areas that include a variety of extreme elevations will require differing flight altitudes to have proper collection parameters. The more variability in elevation, the more flight altitudes are required, resulting in more flightlines.

Vegetation Constraints

Dense vegetation limits the number of laser pulses that can penetrate to the Earth's surface. To compensate for this factor, additional flightlines may be required to increase the overlap and/or increase the angle of penetration, increasing the ability to have some pulses penetrate the canopy. In some cases, increasing the number of pulses may also increase the ability for more pulses to penetrate. In either case, costs increase for processing. In the first case, costs will also increase for collection.

3.2.3. WHAT DATUM, PROJECTION, COORDINATE REFERENCE SYSTEM SHOULD BE APPLIED?

Within the conterminous United States, the horizontal datum and vertical datum should be set to the geometric North American Datum of 1983 (NAD 83 (2011) epoch 2010.0) and the orthometric North American Vertical Datum of 1988 (NAVD 88) (FEMA SID 41), respectively. The only situations where these datums might not be used would be for collection outside the conterminous United States in areas that cannot be connected to the National Spatial Reference System (NSRS). The data should typically be in the Universal Transverse Mercator (UTM) coordinate reference system.

For areas outside the conterminous United States, or which cannot be connected to the NSRS, determinations of datum, projection, and coordinate reference systems must be made by all stakeholders and collection partners prior to data collection. All coordinates (vertical and horizontal) should be in feet. Documentation should indicate whether U.S. Survey Feet or International Feet were used. The U.S. Survey Foot was deprecated on December 31, 2022, in favor of the International Foot (referred to as foot). It may still be necessary to use U.S. Survey Feet for legacy data or for new data collected in locations that have not yet adopted the International Foot convention. The U.S. Survey Foot will not be supported in the modernized NSRS.

3.2.4. WHAT DATA PRODUCTS SHOULD I ORDER?

FEMA standards require compliance with most of the USGS Lidar Base Specification. The USGS specification includes a mandatory suite of deliverables, including classified point clouds, a hydro-flattened DEM, hydro-breaklines used for DEM construction, and extensive project documentation.

In most cases, and virtually always when there are partners jointly funding a project, the full suite of USGS deliverables should be ordered. The FEMA standards do allow omitting hydro-flattening and all or part of the bare earth processing to save costs. Hydro-flattened DEMs are generally not required for a Flood Risk Project but can be helpful. Bare earth processing of the lidar is required in the area of the floodplain. FEMA regions can choose to forgo bare earth processing outside of the floodplain areas or forgo bare earth processing of the entire dataset initially and acquire the necessary bare earth processing through another mechanism. These options exist to allow for innovative approaches in building partnerships to meet the 3DEP goals and are not meant to undermine the 3DEP goal of having national data coverage meeting minimum standards. If a FEMA region chooses to omit standard USGS deliverables in compliance with the exceptions in the FEMA standards, it should coordinate closely with the USGS and 3DEP on a strategy to process these data through other mechanisms so it can become part of 3DEP. Without a solid strategy, omitting these processing steps for short-term cost savings can often result in complications and frustrations.

Breaklines may be needed for hydrologic and/or hydraulic modeling depending on the methods and models used. If hydro-flattening is included, then the USGS specification mandates a number of breaklines be produced. Certain models and methods may require breaklines beyond those mandated by the USGS specification, such as breaklines for streams narrower than 100 feet or breaklines through culverts to maintain hydrologic connectivity. If necessary breaklines are not developed as part of the initial elevation acquisition, they may be developed during hydrologic and/or hydraulic modeling. Overall, data processing and breakline production are likely to be most efficient on a per-unit basis when acquired as part of the elevation data acquisition project. However, if the breaklines are not needed or are not suitable for the modeling to be performed, then an up-front purchase may be wasted. The modelers performing the hydraulic analysis may have a better understanding of which breaklines are needed and how to represent the key features most effectively in the model with breaklines. Most projects will likely follow the USGS specification and thus include breaklines on 100-foot-wide rivers and lakes and ponds greater than 2 acres as part of the base specification. If the FEMA Project Officer knows that the typical modeling approaches in this area need additional breaklines, they may want to include those in the elevation acquisition project. Where possible, consulting with the team that will perform the modeling can help inform this decision.

Contours can be valuable to the hydraulic modeling process and review process but are used less frequently as hydraulic modeling and floodplain delineation become more automated. Contours may be ordered at the time of initial lidar acquisition or be considered during an elevation data integration task during the data development phases. Similar to the production of breaklines, the cost to develop these products is less at the time of acquisition and processing because the larger bare earth dataset is already in the active processing network and does not require extra time to download/upload to networks, etc. However, if they are not going to be used during the hydraulic modeling, they may be an unnecessary expense.

TINs may be produced as part of the DEM development; however, because they are no longer a requirement of most modeling software, purchase and delivery of this dataset is not necessary.

A field survey is required for any new collection, and in some cases, for validation of existing datasets. Ground control and vertical accuracy checkpoints will be collected as dictated by the USGS Lidar Base Specification.

3.3. Leveraged Datasets

In locations where lidar or other high-resolution elevation datasets may already exist, a determination must be made as to whether the dataset can be leveraged for the purposes of Flood Risk Projects. There are several conditions to consider that will determine the validity of the data.

3.3.1. CURRENCY

Currency of the dataset is the first concern that should be addressed. There is no specific age requirement for elevation data. If the area has had a stable population since the data was collected, with relatively few housing tracts in the floodplain or fringes of the floodplain; no major activity, whether human induced or natural, has disturbed the terrain of the area within the floodplain; and no changes to the floodplain structures have occurred, then an older dataset would be considered acceptable. If these activities have occurred in an isolated area within the overall project area, you may desire to only collect new data in this smaller area and use the older dataset for the remainder of the area. There will be trade-offs between the complexity of integrating the older data with the newer data versus the cost of a new collection; the FEMA region should make these decisions case by case.

Care should be taken to validate orthometric heights in areas with suspected vertical motion, which may be caused by land subsidence, uplift, and crustal motion.

3.3.2. METADATA

All terrain datasets should have metadata provided. This metadata should include collection and processing information as well as the vertical accuracy test results. If the metadata is missing, determining the age of the dataset may require additional information from the provider. In the worst case, a comparison between the data and current orthophotography may need to be made to determine validity. If the data appears to fit the orthophotos, then continue with the investigation. If it does not include the correct topographic features, then it should not be used and plans for new acquisition should take place. The data, without metadata, will need consideration of vertical accuracy requirements.

3.3.3. WHAT STANDARDS APPLY?

All leveraged data must meet the vertical accuracy requirements of SID 43.

3.3.4. HOW DO I DETERMINE IF THE DATASET IS APPROPRIATE FOR USE?

Geographic Coverage

Review the dataset to determine whether it has complete coverage of the project area. The coverage should be continuous with no holes or gaps. If coverage is not complete, then a new acquisition should be considered.

Vertical Accuracy Testing

Vertical accuracy test results should be stated in the LAS dataset and/or the DEM metadata as noted earlier. If the testing results meet the vertical accuracy requirements of SID 43, then you will be able to use the dataset. If the requirements are not met, the dataset should not be used. In this case, coordination with the regional point of contact (POC) is recommended to determine the best course of action, which may be acquisition of a new dataset or exploration of alternative leverage datasets.

DEMs derived from lidar datasets that are documented as meeting the vertical accuracy requirements may be considered adequate for use.

When metadata is not provided and the vertical accuracy is unknown, either the dataset should not be used or vertical accuracy testing should be conducted. If the source of the data is reliable and other datasets from this source have proved to meet the vertical accuracy standards, then testing may be the cost-effective approach.

The first resource for accurate test points is existing NGS monuments, state or local benchmarks, or existing survey data. These points must meet the vertical accuracy requirements for checkpoints (see USGS Lidar Base Specification). Checkpoints must be in areas where there has not been change to the terrain in the period since the data were acquired. For example: if an area was forested previously, but is now clear-cut, the area would not be acceptable for the location of a checkpoint. If enough checkpoints to satisfy testing requirements can be located, proceed with testing the data. If additional survey points are required, determine whether the cost is worth the benefit to use the data. If no checkpoints can be located, again determine whether survey points benefit your project.

Once the vertical accuracy test is completed and results are appropriate to meet the SID 43 requirements, then the data can be used. If the results indicate the LAS data does not meet the vertical accuracy requirement, then you will need to consider new acquisition. If the DEM test results do not meet the vertical accuracy requirement by a slight margin, while the LAS data do meet the requirement, the DEM will be adequate for use. If the DEM test results indicate the data is well out of compliance, further investigation may be required, as processing steps that were not correctly completed may result in a DEM that is corrupt or has erroneous elevations. In either case, the DEM would need to be reconstructed from the LAS data and retested. If the LAS data is not available, you will need to consider new acquisition.

3.3.5. WHAT IS THE MOST ACCURATE DATA?

SID 43 requires the use of the most accurate existing topographic data meeting vertical accuracy standards appropriate for the needs of the study and the program. Generally, the data with the highest vertical accuracy will be the most accurate; however, other factors such as the age of the data, the resolution of the data, and the availability of the data should also be considered in the evaluation process. In addition, some datasets may have vertical accuracies so similar that the difference is not significant. Often some professional judgment is required to determine the most accurate data.

Certainly, vertical accuracy as discussed earlier in this document is the most important factor. The comparison of two datasets from the same year, one with a reported vertical accuracy of 15 cm and one with a reported accuracy of 30 cm, would lead you to the most accurate dataset. However, having a reported accuracy of 15 cm does not mean you have an accurate dataset if it is several years old. If there has been major human-made activity or other physical changes during the intervening years, the reported vertical accuracy is meaningless for that area. Thus, age must also be taken into account. Comparing two datasets with similar reported accuracy but eight years difference in age will lead you to recognition of the newer being the more accurate in terms of representing the terrain.

Similarly, different elevation datasets have varying resolution of measurements. Normally, the resolution is correlated with accuracy. DEMs with higher vertical accuracy will typically have denser post spacing. Smaller contour intervals are generally used for higher vertical accuracy. However, you may find two elevation datasets with similar reported vertical accuracy where one has denser post spacing or smaller contour intervals. In general, the higher resolution data are preferable, but this decision also needs to be considered in the context of other data characteristics.

An additional consideration may be whether the dataset is licensed or unlicensed. If the dataset with the best reported vertical accuracy is also the most current, the logical evaluation says this is the most accurate dataset. However, if the dataset is licensed and/or has use restrictions, it may not be the “best” choice. Licensed datasets may be used but can create additional administrative burdens on FEMA and the public to provide access to the data for the due process review of the flood hazard data and potential flood map appeals. For example, take two datasets, one licensed and the other public domain. Both are within the defined highly accurate vertical accuracy range and current as compared to the ground conditions. The public domain dataset may be the best choice, even though the vertical accuracy of the dataset may be slightly less accurate than the licensed dataset. If the licensed data is substantially more accurate, then the licensed dataset must be used. The project officer could also choose to acquire new elevation data of equal or greater accuracy.

Because FEMA is required by law to use the most accurate elevation data available, elevation datasets covering small areas within the overall project must be considered. If these datasets are clearly more accurate than available alternative elevation data for the project, they should be incorporated. The same caveats that the age, resolution, and availability of data with very similar accuracy may all be considered in determining the most accurate data available.

The data must be available prior to the start of the data development phase of a project for SID 43 to apply. It is always a problematic situation when new elevation data become available during a project once the modeling and analysis are underway, or even completed. The best way to manage this situation is to make sure that possible plans for future elevation data collection are thoroughly investigated during Discovery. New elevation data may be acquired by federal, state, or local entities, so coordination requires considerable effort. It is important for the FEMA region to maintain an ongoing dialogue with its states about lidar mapping plans to prevent this issue from occurring. When new data does become available later in the project, SID 43 does not require it to be used, but the region must consider the pros and cons of using or completing the project using existing data. While incorporation of new data later in the project will almost always result in increased costs and schedule delays, that alone is not sufficient reason to move forward with the existing data without considering the new data. An evaluation of the vertical accuracy differences, comparison of the age to current ground conditions, and technological differences should be made to understand the quantitative impacts of not using the data. Moving forward with older data when new data is available will almost always result in a negative perception of the new maps. The goal is to make sure the new products are technically credible.

Elevation data are now available from multiple sensor platforms. Photogrammetric solutions are not used as widely as in past years, but for localized areas, they might still provide the best source of data. Newer techniques using lidar are currently the most prevalent. Interferometric Synthetic Aperture Radar (IFSAR) technology could be a viable alternative in some circumstances, although it does have limitations in dense vegetation and is often licensed. Therefore, an understanding of the technology and its limitations will be important in determining the most accurate dataset.

Many times, as noted earlier in this document, satisfactory existing datasets do not exist. Being aware of state and/or local jurisdictions with multi-year acquisition (update) plans will allow for constructive dialogue and early planning for acquisition of the most accurate available data. Coordination of mapping and acquisition plans will result in the best efficiencies for all parties.

The determination of the "most accurate" dataset is not without its questions and sometimes cloudy answers. The use of professional judgment is the best advice. Comparing the vertical accuracy, accuracy relative to current ground conditions, and the limitations of the datasets, from both legal and technology perspectives, will lead to making the best decision for the specific project.

4. References

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