Guidance for Flood Risk Analysis and Mapping

Elevation Guidance

May 2016

U.S. DEPARTMENT OF HOMELAND SECURITY

FEMA

Requirements for the Federal Emergency Management Agency (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 (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 www.fema.gov/library.

Document History

Affected Section or Subsection	Date	Description
First Publication	Nov 2015	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 USGS LiDAR Base Specifications v1.2, ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0 – November 2014), and ASPRS LAS Specification Version 1.4 – R13 (15 July 2013).
Section 3.4.5	May 2016	The section was added to support the updated standards implementing the elevation requirements from the Biggert Waters Reform Act.

Table of Contents

1.0 Introduction 1

2.0 Elevation Data Basics 1

2.1 Digital Elevation Data 1
2.2 Data Formats 4
2.3 Tiling Scheme 4
2.4 Accuracy 4
2.5 Pulse / Point Spacing 7
2.6 Field Survey 8
3.0 Obtaining Elevation Data for Risk MAP 8

3.1 Acquisition Planning for LiDAR Data 8
3.2 I Need New Acquisition of Elevation Data 10
3.3 Leveraged Datasets 13
4.0 References 17

List of Tables

Table 1: Vertical Accuracy Requirements based on Flood Risk and Terrain Slope within the Floodplain being Mapped 6

Table 2: Land Cover Classes 7

1.0 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 USGS LiDAR Base Specification v1.2, ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0 – November 2014), and ASPRS LAS Specification Version 1.4 – R13 (15 July 2013).

FEMA has standardized on Quality Level 2 data as defined in the USGS LiDAR Base Specification v1.2 for new lidar acquisition consistent with the goals of the 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 light detection and ranging (LDAR) data over the conterminous United States, Hawaii, and the U.S. territories, with data acquired over an 8-year period. Quality Level 2 was selected as the baseline specification for 3DEP because it provides the optimum balance of benefits and affordability.

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

2.0 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, such that they have an understanding of the terrain data utilized 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 just describes 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 Specifications v1.2 glossary.

2.1.1 LiDAR

Light Detection and Ranging (LiDAR) is defined as a laser system that is used to acquire x, y, and z coordinates of terrain and terrain features that are both manmade and naturally occurring. LiDAR systems consist of a Global Positioning System (GPS) with attendant GPS base stations, Inertial Measurement Unit (IMU), and 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, to be utilized for floodplain mapping, involves fixed-wing aircraft mounted laser scanning sensors, thus 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. The time it takes for the emitted light (LiDAR return) to reach the earth's surface (or other feature being measured) and reflect back to the onboard LiDAR detector is measured to determine 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 normally the density or resolution of the data is not 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 Specifications v1.2 and ASPRS Positional Accuracy Standards for Digital Geospatial Data.

A LiDAR deliverable is usually comprised of several different data components; this includes the raw and classified data that is a direct result of the data capture and the derived products.

There are next generation LiDAR sensors in development and beginning to be offered commercially. These are commonly called "photon-counting" or "geiger-mode" lidar sensors. 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 will be useful and cost effective for flood mapping. To-date, technical evaluations of the data from the commercial next generation systems has not yet demonstrated the ability to match conventional systems for effective mapping of ground elevations. 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 is suitable.

2.1.2 LAS Files

Both Raw and Classified Point Cloud data are stored in 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 Version 1.4)

2.1.2.1 Raw Point Cloud

During LiDAR acquisition, sensors collect irregularly spaced mass points through the use of 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.

2.1.2.2 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 in order to separate the points into specific classifications such as buildings, water, vegetation, or bare earth. The final dataset is known as being 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.

2.1.2.3 Bare Earth

Bare Earth is a LiDAR classification that is free from vegetation, buildings, and other man-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 specification. Breaklines are generally derived from the LiDAR data, but might also be collected from orthophotography.

2.1.4 LiDAR Products

2.1.4.1 Digital Elevation Model (DEM)

The digital representation of continuous elevation values at regularly spaced or gridded intervals in x and y directions are known as DEMs. 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.

2.1.4.2 Hydrologically (Hydro) Flattened Digital Elevation Data (DEM)

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 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.

2.1.4.3 Contours

Contours are representative lines 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. Cartographic contours are created and then smoothed via a series of algorithms to produce smooth map quality contours.

2.2 Data Formats

While there are a wide variety of formats for the datasets listed in the preceding section, as described in the USGS LiDAR Base Specifications v1.2, the acceptable formats for FEMA deliverables are prescribed in the Data Capture Technical Reference.

2.3 Tiling Scheme

The USGS LiDAR Base Specifications v1.2 discusses tiling scheme requirements. Tile sizes should take into consideration the end user requirements. Final determination of tiling scheme must be made by all stakeholders and collection partners prior to collection of the data. As noted by both the USGS document, and the Data Capture Guidance – Workflow Details, tiled data must be accompanied by a tile index file.

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 in particular to the requirements for LiDAR datasets, and a generalized description of the testing requirements for these datasets. Additional accuracy requirements and information are found in the USGS LiDAR Base Specifications v1.2.

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 specification requires vertical accuracies based on the American Society for Photogrammetry and Remote Sensing (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 refer to 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 v1.2 for further information and description of these requirements.

SID 40 requires new elevation data purchased by FEMA to comply with the USGS LiDAR Base Specification v1.2 at a minimum. To comply with FEMA Standard 43, existing topographic data leveraged by FEMA must have documentation that it meets the vertical accuracy requirements described in Table 1. The Highest specification level in Table 1 is consistent with the minimum requirements in the USGS specification.

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

*FVA and NVA are reported at the 95% Confidence Level

**CVA and VVA are reported at the 95th Percentile

Prior to the most recent USGS 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 blended the FVA and SVA measurements.

Since much of the leverage data currently available follows the older FVA, SVA, CVA requirements, a crosswalk of these terms is provided in Table 2. A crosswalk of the testing requirements is provided in Table 2. 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

(FVA, fundamental vertical accuracy; NVA, non-vegetated vertical accuracy; SVA, supplemental vertical accuracy; VVA, vegetated vertical accuracy; n/a, not applicable

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 man-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

2.4.2 Accuracy Reporting

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

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 affect the functional accuracy of a data set 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 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 one 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 v1.2 document for further discussion on this topic.

USGS LiDAR Base Specification v1.2 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 the 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 utilized 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 data set and known elevations at specific locations. Field survey conducted under rigorous standards provides these known test elevations. When possible, field survey should be conducted by a 3rd 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 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 v1.2.

3.0 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 prior to commencing Discovery. This provides the biggest benefit from the LiDAR and allows the maximum use of streamlined analyses for the project. SID29 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. The Automated Engineering Analysis (AEA) (First

Order Approximation or FOA) guidance provides strategies to do this. To maximize the benefits and credibility of the AEA, analyses need to be performed using elevation data that meets FEMA's standards. This will ensure that AEA analysis can be used both to validate existing SHFA's, as well as, leveraging the AEA for future regulatory map updates. This approach is likely to produce large efficiencies where the AEA results can be reused on the regulatory maps for previously unmapped or approximate flood zones with low to moderate risk. See the Automated Engineering Analysis Guidance for more detail. 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 3D Elevation Program as a core strategy for partnering on elevation data collections. Collaboration between FEMA and other federal and state agencies will allow for a greater expansion of LiDAR coverage across the nation, and FEMA's Risk MAP program has available the leverage of dollars to help make this coverage possible. Participation in the USGS 3DEP Program allows FEMA to be more proactive in its LiDAR collection, to capture partnerships, even before LiDAR is needed specifically for a Flood Risk Project. With 3DEP underway it is reasonable to assume that over time complete LiDAR coverage will be available in the next 10-15 years. Thus, LiDAR investments should be made with consideration of how a particular purchase will support this national approach.

The critical step to successfully intersecting the 3DEP and Risk MAP Programs, is acquisition planning. Leveraging tools like the Coordinated Need Management Strategy, and ensuring that our Cooperating Technical Partners maintain their business plans can help inform and drive FEMA's decisions on where LiDAR should be purchased. LiDAR can now be considered an investment in future Risk MAP work, rather than only considered after specific needs were identified during Discovery. To ensure that the LiDAR purchased is aligned with Risk MAP priorities, regions need to have a multi-year plan for future work.

Planning for LiDAR acquisition, there are several things that 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 is existing elevation data that meets FEMA's standards or there are substantial contiguous portions of the watershed that are unlikely to require any regulatory map updates. 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 result in the need for future complex collection areas to fill in adjacent unmapped areas. When planning the acquisition area, FEMA Regions should consider the current Risk MAP needs, the efficiency of collecting the planned project and the efficiency of a future projects 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 that will be inefficient to collect in the future. At first this may seem like spending scarce FEMA resources on data FEMA may not need. But, considered in the context of a 3DEP program that will produce complete coverage funded mainly by others, this extra cost is a small investment that will be repaid multiple times over the next 10-15 years.

Led by NOAA and the USGS, the agencies participating in 3DEP have developed the U.S. Interagency Elevation Inventory. This 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 web site, 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 data will likely be required for a flood risk project. In addition, 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 is a critical because it is the planned and potential LiDAR projects in the P4 tool that 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 regions start conversations with other agencies about possible collaboration and partnerships when it comes to the acquisition of purchasing LiDAR and make partners aware of FEMA's plan to help avoid overlaps.

It should be noted, that for the development of flood risk products or hydrologic analyses, not intended for regulatory mapping, high-accuracy elevation data is not required. In this situation, mapping partners may use USGS DEM's or possibly IFSAR, if LiDAR data does not exist. While this is a good solution for many 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 DEM in areas where the data precision will result in negative perceptions of Risk MAP products overall.

3.2 I Need New Acquisition of Elevation Data

3.2.1 What Standards Apply?

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

3.2.2 What Are the Cost Factors?

If the decision is made to purchase LiDAR, there are several factors that must be taken into consideration as they can impact costs.

3.2.2.1 Climate Constraints

Collection requirements as documented in USGS LiDAR Base Specification v1.2 dictate that there be no clouds or fog between the aircraft and the ground, that the ground be free from

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[1] The U.S. Interagency Elevation Inventory is hosted by NOAA's Digital Coast (http://coast.noaa.gov/digitalcoast/). Currently the U.S. Federal Mapping Coordination site is hosted at http://SeaSketch.org, but is expected to migrate to the Federal GeoPlatform in the future.

extensive flooding or inundation as well as snow cover, and preferably during leaf-off conditions. 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 for a prolonged collection period.

3.2.2.2 Geography Constraints

Collection in remote areas in many instances requires additional time and cost. The vendor may need to get the crew and aircraft to a location distant from their base 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.

3.2.2.3 Shape and Size of the Collection Polygon

Following the USGS LiDAR Base Specification v1.2, all collection areas must be buffered by 100 meters such that the data remain 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.

3.2.2.4 Terrain Constraints

Similar to the shape of the collection polygon, terrain constraints may introduce the requirement for additional flightlines. Collection of 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 required, resulting in more flightlines.

3.2.2.5 Vegetation Constraints

Dense vegetation limits the number of laser pulses that can penetrate to the Earth's surface. To compensate for this, 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, and in the first case costs will also increase for collection.

3.2.3 What Datum, Projection, Coordinate Reference System Should be Applied?

The horizontal and vertical datum should be set to NAD83 and NAVD88 (FEMA SID 41) unless there is some consideration for cost or data sharing with another stakeholder for the area being acquired, or collection is outside the Conterminous United States. The data should typically be in Universal Transverse Mercator (UTM) coordinate reference system within the Conterminous United States. Determinations of datum, projection and coordinate reference systems, in areas outside the Conterminous United States, must be made by all stakeholders and collection partners prior to collection of the data. All coordinates (vertical and horizontal) should be in feet.

3.2.4 What Data Products Should I Order?

FEMA standards require compliance with most of the USGS LiDAR Base Specification v1.2. The USGS specification includes a mandatory suite of deliverables including **unclassified and 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 for cost saving. Hydro-flattened **DEM**s 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, but Regions could 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 choses to omit standard USGS deliverables in compliance with the exceptions in the FEMA standards, they should coordinate closely with the USGS and 3DEP on a strategy to complete the processing of these data through other mechanisms so that 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 ft. or breaklines through culverts to maintain hydrologic connectivity. If breaklines are needed that 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 is 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 not suitable for the modeling to be performed, then an up-front purchase may be wasted. The modelers performing the H&H work may have a better understanding of which breaklines are needed and how to most effectively represent the key features 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, consultation 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 for development of these products is less at the time of the acquisition and processing since 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, since they are no longer a requirement of most modeling software, purchase and delivery of this dataset is not necessary.

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 v1.2.

3.3 Leveraged Datasets

In locations where LiDAR or other high-resolution elevation data sets 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 not 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 man induced or natural, has disturbed the terrain of the area within the floodplain; and no changes to the floodplain structures has 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 utilize 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 and these decisions should be made case-by-case by the FEMA Region.

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 orthos, 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 Standard 43 vertical accuracy requirements.

3.3.4 How Do I Determine If The Dataset Is Appropriate For Use?

3.3.4.1 Geographic Coverage

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

3.3.4.2 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 SID43, then you will be able to utilize the dataset. If the requirements are not met, the dataset should not be used. In this case coordination with the Regional 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 which 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 v1.2.) 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 the testing of the data. If additional survey points are required, determine whether the cost is worth the benefit to utilize 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 SID43 requirements, then the data can be used. If the results indicate the LAS data do 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 are well out of compliance, further investigation may be required as processing steps that were not correctly complete may result in a DEM that is corrupt or has erroneous elevations. In this case, the DEM would need to be reconstructed from the LAS data and re-tested. If the LAS data is not available, you will need to consider new acquisition.

3.3.5 What is the Most Accurate Data?

SID43 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 15cm and one with a reported accuracy of 30cm, would lead you to the most accurate dataset. However, having a reported accuracy of 15cm does not mean you have an accurate dataset if it is several years old. If there has been major manmade activity or other physical changes during the intervening years, the reported vertical accuracy is meaningless for that area. Thus, currency must also be taken into account. Comparison of two datasets with similar reported accuracy but 8 years difference in age, will lead you to recognition of the newer being the most accurate in terms of representing the terrain.

Similarly, different elevation data sets 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 data sets with similar reported vertical accuracy where one has denser post spacing or smaller contour intervals. In general, the higher resolution data is preferable but this also needs to be considered in the context of other characteristics of the data.

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 data sets may be used, but 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 data sets covering small areas within the overall project must be considered. If these data sets are clearly more accurate than alternative available 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 becomes available during a project once the modeling and analysis is 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 that the Region maintains an ongoing dialogue with their states about LiDAR mapping plans to help avoid this issue from occurring. When new data does become available later in the project, SID 43 does not require it must 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 currency as compared to 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 and this must be considered as well. The goal is to make sure the new products are technically credible.

Elevation data is 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 both 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. Comparisons of the datasets in terms of vertical accuracy, currency when compared to the ground conditions, and understanding the limitations of the datasets from both legal and technology perspectives will lead to making the best decision for the specific project.

4.0 References

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