

State of Tennessee Enhanced Elevation Technical Specifications



FINAL DELIVERABLE

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Produced by



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FOREWORD AND ACKNOWLEDGEMENTS

Through a grant awarded by the Federal Geographic Data Committee (FGDC) in March 2011, the OIR-GIS has developed a business plan for enhanced elevation. A consulting team led by Applied Geographics, Inc. with support from AECOM Technical Services, Inc. assisted OIR-GIS with development of the business plan and with the development of these specifications. Over 160 members of the statewide community engaged in five regional workshops and approximately 75 people participated in 20 interviews and provided input to the plan and specifications.

A steering committee guided the business planning process and its members were:

Brock Hill, Chairman	Asst. Commissioner, Tennessee Dept. of Environment and Conservation
Dan Hawk	Tennessee Economic and Community Development
Jim Waters	Tennessee Dept. of Transportation - (Design Division)
Keith McFadden	US Geological Survey
Jason Duke	US Fish & Wildlife Service, Tennessee Geographic Information Council
Dave McMillen	US Dept. of Agriculture, Natural Resource Conservation Service
Jennifer Higgs	Nashville Metropolitan Planning Commission

In addition to the steering committee, members of the Enhanced Elevation Technical Committee, representing several Federal agencies, State agencies, and local government, provided guidance and feedback in the development of the Enhanced Elevation Technical Specifications.

Coincidental and complementary to the business plan project undertaken by OIR-GIS Services, was a study by the US Geological Survey (USGS) for a National Enhanced Elevation Assessment (NEEA). Reference material provided in interviews on the NEEA and USGS LiDAR specification (version 13) are utilized in this document. Results of the NEEA are anticipated to be published in December 2011.

The specifications herein are an update to the previous Tennessee LiDAR Mapping Program Technical Specification, originally issued on October 14, 2010 by OIR-GIS and the Tennessee Department of Transportation.



1 INTRODUCTION

The State of Tennessee seeks to create and acquire an enhanced elevation resource as part of the Tennessee Base Mapping Program. The resource will meet the needs of many stakeholders for the development of statewide flood risk maps and mitigation plans, emergency response, hydrologic and watershed investigations, telecommunication planning and analysis, utilities and public works improvements, aerial photo ortho-rectification, and other business functions that depend on high accuracy measurement of topographic conditions.

The term **enhanced elevation** refers to precise 3-dimensional measurements of land or submerged topography, built features, vegetation structure, and other landscape detail. LiDAR (Light Detection and Ranging) technology will be used to create the enhanced elevation products under contract(s) with qualified photogrammetric, engineering, and/or surveying firms.

Products derived from this specification will serve to supplement and enhance the existing GIS data resources produced and sustained through the Tennessee Base Mapping Program (TNBMP), which was initiated by the Comptroller of the Treasury, Division of Property Assessments in 1996. Program management and GIS coordination functions were shifted to the Department of Finance and Administration, Office for Information Resources, GIS Services (OIR-GIS) in 1998. The initial production efforts of the TNBMP were completed in 2007. Maintenance responsibility for TNBMP GIS data is assigned to OIR-GIS in partnership with other State agencies.

Floodplain mapping and related emergency response and mitigation planning is the predominant business case and motivation for development of a statewide enhanced elevation resource. Through a partnership with the Department of Economic and Community Development (ECD), OIR-GIS and ECD have worked in support of FEMA's Flood Map Modernization program. Now branded as Risk MAP, OIR-GIS is continuing to work with FEMA through coordination and GIS training efforts in Tennessee to increase public awareness of flood risk across the state. In 2012, this partnership has expanded, and OIR-GIS is now identified by FEMA as a Cooperating Technical Partner (CTP). Together, OIR-GIS and FEMA will strive to identify, procure, and collect the most accurate set of digital terrain data to support Risk MAP and other needs for enhanced elevation data.



The specifications herein support base deliverable products that meet or exceed minimum requirements for flood risk mapping as published in *Federal Emergency Management Agency's Map Modernization – Guidelines and Specifications for Flood Hazard Mapping Partners, Procedures Memorandum 61: Standards for LiDAR and Other High Quality Digital Topography (2010)*. The standard products are sufficiently accurate to generate the equivalent of 2' contours traditionally used by local government. An optional upgrade product is also part of this plan, and is suitable to generate the equivalent of 1' contours. Together, the standard and upgrade products will serve many requirements of the statewide geospatial community.



2 DATA ACCURACY

All LiDAR data must meet or exceed the standard product specifications described in this document.

Stakeholder accuracy needs were assessed, in part, by using the chart provided in *Table 1. Quality Levels for Enhanced Elevation, U.S. Geological Survey National Enhanced Elevation Assessment*, later in this section. In the chart, a series of horizontal resolution and vertical accuracy ‘levels’ were provided to help determine elevation accuracy needs for specific business functions of stakeholders. Quality Level 3 (QL3) in the chart was determined to be closest to the minimum level of elevation data required to support the majority of stakeholder requirements, but not all. Flood risk mapping is the most predominant business driver for creating an enhanced elevation resource, and the QL3 meets or exceeds elevation specifications for most risk levels (highest excluded) per the *Federal Emergency Management Agency’s (FEMA) Guidelines and Specifications for Flood Hazard Mapping Partners, Procedures Memorandum 61: Standards for LiDAR and Other High Quality Digital Topography*, which is available at the following URL: <http://www.fema.gov/library/viewRecord.do?id=4345> .

In order to meet or exceed the specifications for all risk levels and overall program needs, **the minimal requirement for the TNBMP standard deliverable has a higher vertical accuracy requirement than the USGS QL3**, that is, 12.5 cm RMSE in open terrain (Fundamental Vertical Accuracy, FVA) with a nominal pulse spacing (NPS) of 1.0 meters.



**Table 1. Quality Levels for Enhanced Elevation, U.S. Geological Survey
National Enhanced Elevation Assessment, June 2011**

Quality Levels	Elevation Source	Horizontal Resolution Terms			Vertical Accuracy Terms	
		Point Density	Nominal Pulse Spacing	NED Post Spacing	RMSEz in Open Terrain *	Equivalent Contour Accuracy
QL 1	LiDAR	8 pts/m ²	0.35 m	1/27 arc-sec (~1 m)	9.25 cm	1-ft
QL 2	LiDAR	2 pts/m ²	0.7 m	1/27 arc-sec (~1 m)	9.25 cm	1-ft
QL 3	LiDAR	1 – 0.25 pts/m ²	1 – 2 m	1/9 arc-sec (~3 m)	≤18.5 cm	2-ft
QL 4	Imagery	1 – 0.04 pts/m ²	1 – 5 m	1/3 arc-sec (~10 m)	46.3 cm – 139 cm	5 – 15 ft
QL 5	IFSAR	0.04 pts/m ²	5 m	1/3 arc-sec (~10 m)	92.7 cm – 185 cm	10 – 20 ft

2.1 HORIZONTAL AND VERTICAL ACCURACY

For the standard product, bare-earth terrain data must be capable of supporting two-foot contour accuracy. Vertical accuracy of the LiDAR data will be assessed and reported in accordance with *Guidelines for Digital Elevation Data*, developed by the National Digital Elevation Program (NDEP) and subsequently adopted by the American Society for Photogrammetry and Remote Sensing (APPRS). The test for the vertical accuracy is conducted in five land cover categories: open terrain; high grass and crops; brush and low trees; fully forested; and urban areas. Fundamental Vertical Accuracy (FVA) is based entirely on the open terrain cover type; Consolidated Vertical Accuracy (CVA) includes checkpoints from all cover types. Supplemental Vertical Accuracy (SVA) is reported separately on each of the remaining four cover types. Additional information for the test are found in Section 1.5 Data Quality of the Guidelines at www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf.



Standard product vertical accuracy requirements using the NDEP/ASPRS methodology are:

Fundamental Vertical Accuracy ≤ 24.5 cm ACCz, 95% (12.5cm RMSEz)

Consolidated Vertical Accuracy ≤ 36.3 cm, 95th Percentile

Supplemental Vertical Accuracy ≤ 36.3 cm, 95th Percentile

Horizontal accuracy shall be tested to meet or exceed an RMSE of one-half of the nominal pulse spacing of the LiDAR data or 3 foot at the 95% confidence level for LiDAR data with nominal pulse spacing of 1.0 meters (using $RMSE^{\circ} \times 1.7308$ as defined by the FGDC Geospatial Positional Accuracy Standards, Part 3: NSSDA).

2.2 PROJECT AREA AND TILING SCHEME

Tennessee OIR-GIS seeks sustainable funding source(s) to acquire seamless enhanced elevation coverage across the state. Under a fully funded scenario, the program will likely acquire enhanced elevation data in 4 annual increments by region. Regional boundaries for the project areas will be coincident with county boundaries and/or the 8-digit hydrologic units as defined by USDA/USGS (HUC8). The base tiling scheme for collection of LiDAR data products and flight mission planning will be the County Index of Property Maps. The Comptroller of the Treasury, Division of Property Assessments (DPA) developed a countywide index for each county in the state during the cadastral mapping program in the 1960s. The county index is that portion of the Tennessee State Plane Coordinate grid that overlaps the total area of the county. The individual grid cells in the county index have dimensions of 14,000 x 8,000 feet and are typically published at a map scale of 1"=400'. The numbering system usually starts in the upper left portion of the county with map one and continues sequentially from top to bottom until all grid cells that fall within the county are numbered (Figure 1). The total number of 1" = 400' maps depends on the size of a county and usually range between 100 and 200 map sheets. The 1"= 400' map sheets are the foundation of the Tennessee Base Mapping Program and are essential units for developing and maintaining digital map data.

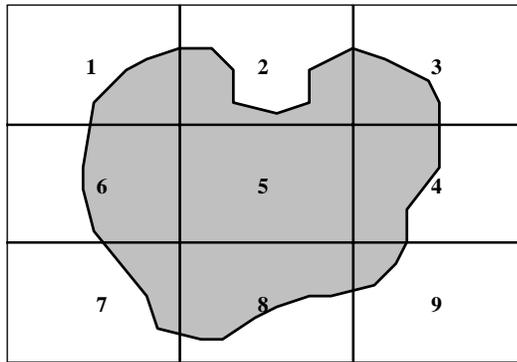


Figure 1. Map Sheet Numbering Scheme

Prior to data acquisition, the State will provide the contractor with an Esri shapefile that identifies the geographic extent of the LiDAR coverage area. The project areas are to be made up of a collection of 14,000-ft-by-8,000-ft cells that will serve as the tiling scheme for the base deliverables. The tiling structure may be further divided into 16 subunits of 3,500' x 2,000' for task orders where higher point densities are acquired. On projects that are part of a statewide program operating on a regional cycle, the contractor(s) is required to make seam-less joins with previously collected data along project boundaries.



3 DATA ACQUISITION

The Tennessee Base Mapping Program (TNBMP) specifications for the standard product is 12.5 cm RMSE vertical accuracy in open terrain (Fundamental Vertical Accuracy, FVA) with a nominal pulse spacing (NPS) of 1.0 meters. The mapping will be suitable for generation of 2' contours as an optional service. Specifications for the optional upgrade product are 9.25 cm RMSE FVA with a NPS of 0.7 meters.

Table 2. Comparison of Tennessee LiDAR Project Specifications provides recent and planned project information comparing specifications with the TNBMP standard and upgrade products.

Table 2. Comparison of Tennessee LiDAR Project Specifications

PROJECT	SPECIFICATION		
	Vertical Accuracy, FVA RMSE, in centimeters	Equivalent Contour Accuracy, in feet	Nominal Pulse Spacing, in meters
USGS NEEA QL3	18.5	2	1-2
USGS NEEA QL2	9.25	1	0.7
USGS NEEA QL1	9.25	1	0.35
USGS Version 13	12.5	-	1-2
Anderson County Project	76.2	5	4.5
Rutherford County Project	15 - 18	1	5.0
Hamilton County Project w/ USGS and NGA	-	2	.9 / .68
KGIS, Knoxville, Knox County Project	18.5	2	1.0
Nashville, Davidson County Project w/ USGS	12.5	-	1-2
Lauderdale County Project w/ USDA	18.5/9.25	2/1	0.7/.5
USDA -NRCS West TN Projects 5600 sq. mi.	9.25	1	.7
TNBMP Standard	12.5	2	1
TNBMP Upgrade	9.25	1	0.7



3.1 DESCRIPTION OF BASE DELIVERABLES

Point Cloud

Contractor(s) is to deliver an **unclassified LiDAR point cloud** (LAS 1.2) for the coverage area specified in each RFQ/task order. Sensors should include capabilities to collect up to 3 or more multiple discrete returns including the first and last returns. In addition to the return values, the intensity value for each pulse shall be included. Point cloud data shall include GPS time, intensity data, and the headers shall include the date of collection. Data voids and gaps in the LiDAR point cloud are unacceptable, except over water surfaces and fresh asphalt.

Contractor(s) is to also deliver a **classified LiDAR point cloud** (LAS 1.2). All LiDAR points must be classified according to American Society of Photogrammetry and Remote Sensing (ASPRS) guidelines and stored in LAS format for easy retrieval and usability.

ASPRS minimum classifications should be:

Unclassified (non-ground) – Class 1

Ground (bare-earth extra points) – Class 2

Noise – Class 7

Model Key Point (thinned bare-earth) – Class 8

Water – Class 9

Overlap Points (overlap from adjoining flight lines) – Class 12

Additional elements of the **classified LiDAR point cloud** deliverable:

- A complete LiDAR point cloud shall be delivered where the bare earth classification (Class 2) is free of features not representing the earth's surface (e.g. cell towers, building, trees, vehicles, etc.). These features shall be classified as Class 1.
- LiDAR points inside of water bodies will be classified as water Class 9. Water bodies are defined as standing water bodies => 1 acre and streams or rivers => 50 feet.



- The model key, which is a subset of the bare earth point which represents a critical abrupt change in the terrain slope, should be classified as Class 8.
- Class 12 will be used for LiDAR points in areas of overlapping flight lines, which have been deliberately deleted and removed from point cloud because of their reduced accuracy, possibly due to their off-nadir position.
- All noise and blunder points shall be classified as Class 7.
- Public header information must be contained as specified within the LAS 1.2 file specification. In addition to the LAS 1.2 required fields, the following items are required to be populated:
 - Project ID – GUID data 1: project identifier
 - File Creation Day of Year: 1
 - File Creation Year: year created
- The fields File Creation Day of Year and File Creation Year are the file creation date. This date will represent the day the final LAS file is generated for submittal.
- Projection information for the point data must be specified in the Variable Length Records using the GeoTIFF specification as the model, as defined in the LAS 1.2 file specification.
- The Point Data Record Format shall follow the Point Data Record Format 1, as defined in the LAS 1.2 Specification. In addition to the required items, the intensity shall be populated.

Digital Elevation Model (base earth)

Contractor(s) is to deliver a **Digital Elevation Model (DEM)** of bare earth conditions with 1 meter grid cells. The DEM is to be hydro flattened using 3-D breaklines. Any raw data or extraneous values are to be processed to provide ground-level, surface elevations or “bare-earth” DEMs devoid of vegetation or man-made structures. The hydro flattening term is relatively new and recently coined by the US Geological Survey for integration of DEMs into the National Elevation Dataset (NED). DEMs intended for incorporation into the National Elevation Dataset must be hydro flattened. Hydro flattening refers to the process of ‘flattening’ water bodies in the DEM with further definition offered in USGS NGP LiDAR Guidelines and Base Specification February 22, 2010 Version 13 – ILMF 2010. Hydro flattening is not to



be confused with 'hydro conditioning' and 'hydro enforcement', which involve processing to remove unintended sinks in the surface model and additional flow considerations to support engineering studies.

Hydro flattening of Inland Ponds and Lakes:

1-acre or greater surface area at the time of collection. Flat and level water bodies (single elevation for every bank vertex defining a given water body). The entire water surface edge must be at or below the immediately surrounding terrain. Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, should be treated as rivers.

Hydro flattening of Inland Streams and Rivers:

50' nominal width. This should not unnecessarily break a stream or river into multiple segments. At times it may squeeze slightly below 50' for short segments. Data producers should use their best professional judgment. Flat and level bank-to-bank (perpendicular to the apparent flow centerline); gradient to follow the immediately surrounding terrain. The entire water surface edge must be at or below the immediately surrounding terrain. Streams channels should break at road crossings (culvert locations). These road fills should not be removed from DEM. However, streams and rivers should not break at elevated bridges. Bridges should be removed from DEM. When the identification of a feature as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.

3-D Breaklines

Contractor(s) is to deliver the 3-D breaklines used to hydro-flatten the DEM. All breaklines developed for use in hydro-flattening shall be delivered as an Esri feature class (PolylineZ or PolygonZ), and geodatabase format is preferred over Esri shapefile. Each feature class or shapefile will include properly formatted and accurate georeference information in the standard location. All shapefiles must include the companion.prj file.

Breaklines must use the same coordinate reference system (horizontal and vertical) and units as the LiDAR point cloud delivery, identified in section 3.2 as the Tennessee State Plane (FIPS Zone 4100).



Breakline delivery will be in tiles and features must edge-match seamlessly in both the horizontal and vertical.

Intensity Images

Contractor(s) is to deliver a raster image of the intensity measurements for 1st return data. The intensity image will be provided as 1 meter grid and tiled to the format described in Section 2.2, and delivered in GeoTIFF format. Projection and coordinate systems to be compatible with base deliverables as referenced in Section 3.2.

Project Metadata

Federal Geographic Data Committee compliant metadata, project and group level.

3.2 GEODETIC DATUM, COORDINATE SYSTEMS, AND UNITS OF MEASURE

The survey should be performed as follows:

- Horizontal coordinates shall be U.S. Survey Foot to at least two decimal places, Tennessee State Plane (FIPS Zone 4100) coordinate system.
- Horizontal datum shall be referenced to the North American Datum of 1983, North American Plate National Adjustment of 2011, otherwise referred to as NAD 83 (2011).
- Elevations shall be U.S. Survey Foot to at least two decimal places, vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88-Geoid12).
- GPS surveys will be tied to the NAD 83 (2011), including TDOT GNSS Reference Network stations.

3.3 ACQUISITION REQUIREMENTS

- Cloud and fog-free between aircraft and ground.
- Ground to be free of snow and no unusual flooding or inundation, unless requirement is waived in advance.



- LiDAR sensor shall be capable of recording up to 3 (or more) returns per pulse, including 1st and last returns.
- Scan Angle of LiDAR sensor must be less than +/- 20 degrees off nadir.
- Swath Overlap: Nominal sidelap on adjoining swaths shall be 30% coverage.
- GPS Procedures: At least two TDOT GNSS Reference Network stations in operation during all missions with baseline distances for GPS ground control not to exceed 50 miles.
- Data Collection Season: During leaf-off season - late fall and winter (depending on area of State), usually between early December and late March, unless otherwise agreed upon.
- Project level metadata are required for LAS (point cloud) data that fully comply with Federal Geographic Data Committee (FGDC) metadata standards.
- LAS delivery tile size will 14,000 foot x 8,000 foot cells subject to further sub-tiling with higher resolution collections. See (Sec 2.2).
- Delivery will be completed by county or region, depending on the task order.
- Contractor shall ensure that all parts of the county or region specified in the task order are fully covered. No portion of the project area is to be omitted from collection and processing.
- Data gaps between adjacent flight lines are not acceptable.
- No data voids due to system malfunctions or lack of overlap.

3.4 GEOGRAPHIC COVERAGE AND CONTINUITY

Tennessee OIR-GIS intends to provide statewide seamless coverage of enhanced elevation encompassing the entire State of Tennessee. A potential to extend the coverage into adjoining states to allow coverage of complete hydrologic units may exist. When the program becomes fully funded, an acquisition schedule will be determined and publicized. A popular scenario which has been discussed among stakeholders is to develop a regional acquisition schedule, where one-third or one-fourth of the state is acquired on a 3 or 4 year cycle. There is no guarantee of funding to support this approach, and a less aggressive, scaled back approach may be required due to economic conditions.



3.5 LIDAR MAPPING SURVEY CONTROL

- For the standard product at 12.5 cm RMSE vertical accuracy (FVA) with 1.0 meter LiDAR pulse spacing, the vertical ground control must be accurate to 4 cm RMSE.
- Density and distribution of the ground control should ensure accuracy of the final deliverables.
- A survey report that documents and certifies the procedures and accuracies of the horizontal and vertical control, aircraft positioning systems, and system calibration procedures used in the LiDAR mapping project shall be created.
- The horizontal and vertical control shall be based on direct ties to National Geodetic Survey (NGS) control stations, National Spatial Reference System (NSRS). All geodetic control surveys, both horizontal and vertical, shall conform to the Standards and Specifications for Geodetic Control Networks (1984), Federal Geodetic Control Committee (FGCC).
 - The horizontal control shall reference the NAD 83 (2011). Procedures used to establish horizontal photogrammetric ground control using GPS measurements shall meet or exceed Second Order Horizontal Control as set forth by the FGCC, Geometric Geodetic Accuracy Standards and Specifications for using GPS Relative Positioning Techniques, Version 5.0, May 1988.
 - The vertical control shall reference the North American Vertical Datum of 1988 (NAVD88) using Geoid12 to perform conversions from ellipsoidal heights to orthometric heights. Procedures used to establish vertical control shall meet or exceed Third Order Vertical Control Accuracy Standards and Specifications. Procedures for GPS-Derived elevation differences shall meet or exceed Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm), NGS-58, November 1997, and/or Guidelines for Establishing GPS-Derived Orthometric Heights (Standards: 2 cm and 5 cm), NGS-59, October 2005.
 - A text report that describes the survey methods, results and contractor accuracy assessments, including internal consistency and absolute accuracy, file formats, file naming schemes, and tiling schemes.



4 STANDARD PRODUCT DELIVERABLES (SUMMARY)

4.1 SURVEY REPORT METADATA

Detail the collection of control and reference points used for calibration and QA/QC

4.2 PROCESSING REPORT METADATA

Detail calibration, classification, and product generation procedures including methods used for breakline collection and hydro flattening

4.3 AIRCRAFT TRAJECTORIES METADATA

The actual trajectory of the acquisition is to be provided in Esri shapefile format with all necessary attributes, at minimum, flightline name, beginning and ending timestamps

4.4 ALL RETURN POINT CLOUD

- a. Unclassified all return point cloud in LAS 1.2 format. FGDC compliant group level metadata.
- b. Classified all return point cloud in LAS 1.2 format. FGDC compliant group level metadata.

4.5 GROUND (BARE EARTH) SURFACE MODEL HYDRO-FLATTENED AND 3-D BREAKLINES

- a. Digital elevation model (DEM) of ground surface (1 meter grid), hydro flattened with 3-D breaklines. Surface Models shall have no tiling artifacts, no gaps and no artificial smoothing at tile boundaries

File format in Esri GRID. FGDC compliant group level metadata.

- b. 3-D breaklines suitable to support hydro-flattening as an Esri geodatabase. FGDC compliant group level metadata.

4.6 MICROSTATION POINTS AND BREAKLINE FILE REQUIREMENTS

- a. A ground (bare earth) MicroStation 3-D graphic *.dgn file will be required that contains spot



elevations and breaklines. The level and symbology of these graphic elements shall follow the values defined in the standard level structure found in document file CADDV8.pdf available at http://www.tdot.state.tn.us/Chief_Engineer/assistant_engineer_design/design/v8/v8design.htm.

- b. A bridge decks MicroStation 3-D graphic *.dgn file will be required that contains spot elevations and breaklines of bridge decks. The level and symbology of these graphic elements shall follow the values defined in the standard level structure found in document file CADDV8.pdf at the same link provided in 4.6.a above.

4.7 INTENSITY IMAGES

Raster intensity image of first returns in GeoTIFF format, 1 meter pixel size tiled (14,000 x 8,000 feet). FGDC compliant group level metadata.



5 UPGRADE PRODUCT AND OPTIONAL SERVICES

5.1 UPGRADE PRODUCT – 9.25 CM RMSE FVA AND 0.7 NPS

The Tennessee Base Mapping Program enhanced elevation specification for the upgrade product requires a vertical accuracy of 9.25 cm RMSE for FVA with nominal pulse spacing of 0.7m and is suitable to generate a contour equivalent of 1 foot. The vertical accuracy testing requirements using the NDEP/ASPRS guidelines and methodology are:

Fundamental Vertical Accuracy \leq 18.2 cm ACCz, 95% (9.25 cm RMSEz)

Consolidated Vertical Accuracy \leq 27.3 cm, 95th Percentile

Supplemental Vertical Accuracy \leq 27.3 cm, 95th Percentile

Horizontal accuracy shall be tested to meet or exceed an RMSE of one-half of the nominal pulse spacing of the LiDAR data or 3-foot at the 95% confidence level for LiDAR data with nominal pulse spacing of 0.7 meters (using $RMSE^{\circ} \times 1.7308$ as defined by the FGDC Geospatial Positional Accuracy Standards, Part 3: NSSDA).

For the upgrade product at 9.25 cm RMSE vertical accuracy (FVA) with 0.7 meter LiDAR pulse spacing, the vertical ground control must be accurate to 3 cm RMSE.

5.2 CONTOURS (1 OR 2 FOOT INTERVALS (DEPENDENT UPON STANDARD OR UPGRADE PRODUCT), DETAILED SPECIFICATIONS ISSUED WITH TASK ORDER)

Contour Level 3 (CL3): Typically auto-generated, moderately aesthetic and consistent with an acceptable level of smoothing.

Contour Level 2 (CL2): Typically auto-generated with some manual enhancements, aesthetically pleasing with acceptable cartographic style.

Contour Level 1 (CL1): High quality cartographic style with high end smoothing, full attribution of index contours, depressions, sinks.



5.3 HYDRO ENFORCED BARE EARTH ELEVATION MODEL (50' GRID)

The manual stereo compilation of 3D breaklines using stereo pairs generated from LiDAR intensity and surface is required to generate this product. The stereo pairs should be generated at a GSD that does not exceed the nominal LiDAR pulse spacing. Breaklines specified in the base product deliverables do not support Hydro enforcement.

5.4 BUILDING OUTLINES

All visible freestanding structures shall be collected and included as topologically correct polygon features. The minimum structure that is to be collected from the LiDAR intensity images shall be 1000 square feet. The building footprint is acceptable for depicting the building outline. Buildings to be delivered as an Esri geodatabase feature class.

5.5 DIGITAL SURFACE MODEL

An elevation model created to depict the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare earth



6 GLOSSARY OF TERMS

BARE EARTH TERRAIN - Digital elevation data of the terrain, free from vegetation, buildings, and other man-made structures. Elevations of the ground are derived from pulse-processing of LiDAR data. Automated and manual pulse-processing routines are used to eliminate points that impinge on elevation features.

BREAKLINE – A linear feature demarking a change in the smoothness or continuity of a surface such as abrupt elevation changes or a stream line.

CONSOLIDATED VERTICAL ACCURACY (CVA) – The result of a test of the accuracy of vertical checkpoints (z-values) consolidated for two or more of the major land cover categories, representing both open terrain and other land cover categories. Computed by using the 95th percentile, CVA is always accompanied by Fundamental Vertical Accuracy (FVA).

DIGITAL ELEVATION MODEL (DEM) - A popular acronym used as a generic term for digital topographic and/or bathymetric data in all its various forms, but most often bare earth elevations at regularly spaced intervals in x and y directions. Regularly spaced elevation data are easily and efficiently processed in a variety of computer uses. A digital elevation model (DEM) contains elevations at points arranged in a raster data structure, a regularly spaced x, y grid, where the intervals of Δx and Δy are normally in linear units (feet or meters) or geographic units (degrees or fractions of degrees of latitude or longitude). The z-values in a DEM represent the height of the terrain, relative to a specific vertical datum and void of vegetation or manmade structures such as buildings, bridges, walls, et cetera. The elevation of lakes and rivers in a DEM implies the height of the water surface based on elevation of the exposed shoreline. The observations, or direct measurements, of elevation that comprise the DEM are almost never actually captured on a regular grid; therefore, the elevation for any given point in the grid is normally interpolated from other forms of source data. LiDAR, for example, yields a dense set of irregularly spaced points; interpolation to a grid requires using one of many possible interpolation algorithms, which produce varying results. Linear features, such as streams, drainage ditches, ridges, and roads are often lost in a DEM if the grid spacing is larger than the dimensions of the feature. Furthermore, in a DEM, it is unlikely that the sharp edge of the feature will be represented correctly in the terrain model.



The DEM, because it is a raster data structure similar to a digital image, is an efficient format for storage, analysis, rendering, and visualization.

DIGITAL SURFACE MODEL (DSM) – An elevation model created for use in computer software that is similar to DEMs or DTMs except that DSMs depict the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare earth.

ENHANCED ELEVATION - Precise 3-D measurements of land or submerged topography, built features, vegetation structure, and other landscape detail.

FUNDAMENTAL VERTICAL ACCURACY (FVA) – The value by which vertical accuracy can be equitably assessed and compared among datasets. The FVA is determined with vertical checkpoints located only in open terrain, where there is a very high probability that the sensor will have detected the ground surface. FVA is calculated at the 95% confidence level in open terrain only, using $RMSE_z \times 1.9600$.

HILLSHADE - A function used to create an illuminated representation of a surface, using a hypothetical light source that simulates the cast shadow thrown upon a raised relief map. This process is helpful in identifying linear features such as streams and ridgelines.

HYDROLOGICALLY-ENFORCED (Hydro-Enforced) – Processing of mapped water bodies so that lakes and reservoirs are level and so that streams flow downhill. For example, a DEM, TIN or topographic contour dataset with elevations removed from the tops of selected drainage structures (bridges and culverts) so as to depict the terrain under those structures. Hydro-enforcement enables hydrologic and hydraulic models to depict water flowing under these structures, rather than appearing in the computer model to be dammed by them because of road deck elevations higher than the water levels. Hydro-enforced TINs also utilize breaklines along shorelines and stream centerlines, for example, where these breaklines form the edges of TIN triangles along the alignment of drainage features. Shore breaklines for streams would be 3-D breaklines with elevations that decrease as the stream flows downstream; however, shore breaklines for lakes or reservoirs would have the same elevation for the entire shoreline if the water surface is known or assumed to be level throughout.

LAS - The ASPRS LAS file format is a public file format for the interchange of 3-dimensional point cloud data between data users. Although developed primarily for exchange of LiDAR point cloud data, this



format supports the exchange of any 3-dimensional x-y-z tuplet. This binary file format is an alternative to proprietary systems or a generic ASCII file interchange system used by many companies.

LiDAR - is an acronym for Light Detection and Ranging. LiDAR is synonymous with airborne laser mapping and laser altimetry. A LiDAR sensor is an instrument that measures distance to a reflecting object by emitting timed pulses of laser light and measuring the time between emission and reception of reflected pulses. The measured time interval is converted to distance.

NATIONAL DIGITAL ELEVATION PROGRAM - With an ever growing demand for digital elevation data by Federal, state, and local governments, the National Digital Elevation Program (NDEP) was established to promote the exchange of digital elevation data among government, private, and nonprofit sectors and the academic community, and to establish standards and guidance that will benefit all users. The NDEP currently consists of representatives from approximately 12 federal agencies and the National States Geographic Information Council (NSGIC).

NOMINAL PULSE SPACING (NPS) – The estimated average spacing of irregularly-spaced LiDAR points in both the along-track and cross-track directions resulting from: the laser pulse repetition frequency (e.g., 100,000 pulses of laser energy emitted in one second from a 100 kHz sensor); scan rate (sometimes viewed as the number of zigzags per second for this common scanning pattern); field-of-view; and flight airspeed. LiDAR system developers currently provide “design NPS” as part of the design pulse density, although the American Society for Photogrammetry and Remote Sensing (ASPRS) is currently developing standard procedures to compute the “empirical NPS” which should be approximately the same as the “design NPS” when accepting statistically insignificant loss of returns and disregarding void areas, from water for example. The NPS assessment is made against single swath first return data located within the geometrically usable center portion (typically ~90%) of each swath. Average along-track and cross-track pulse spacing should be comparable. When point density is increased by relying on overlap or double-coverage it should be documented in metadata, and the project’s reported NPS should not change. The NPS should be equal to or less than the Digital Elevation Model.

POINT CLOUD - Often referred to as the “raw point cloud”, this is the first data product of a LiDAR instrument. In its crudest form, a LiDAR raw point cloud is a collection of range measurements and sensor orientation parameters. After initial processing, the range and orientation of each laser value is converted to a position in a three dimensional frame of reference and this spatially coherent cloud of



points is the base for further processing and analysis. The raw point cloud typically includes first, last, and intermediate returns for each laser pulse. In addition to spatial information, LiDAR intensity returns provide texture or color information. The combination of three dimensional spatial information and spectral information contained in the LiDAR dataset allows great flexibility for data manipulation and extraction.

ROOT MEAN SQUARE ERROR (RMSE) – The square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The vertical RMSE (RMSE_z), for example, is calculated as the square root of $S(Z_n - Z'_n)^2/N$, where: **Z_n** is the set of N z-values (elevations) being evaluated, normally interpolated (for TINs and DEMs) from dataset elevations of points surrounding the x/y coordinates of checkpoints **Z'_n** is the corresponding set of checkpoint elevations for the points being evaluated **N** is the number of checkpoints **n** is the identification number of each of the checkpoints from 1 through N.

SUPPLEMENTAL VERTICAL ACCURACY (SVA) – The result of a test of the accuracy of z-values over areas with ground cover categories or combination of categories other than open terrain. Computed by using the 95th percentile, SVA is always accompanied by Fundamental Vertical Accuracy (FVA). SVA values are computed individually for different land cover categories. Each land cover type representing 10% or more of the total project area is typically tested and reported as an SVA. SVA specifications are normally target values that may be exceeded so long as overall CVA requirements are satisfied.



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