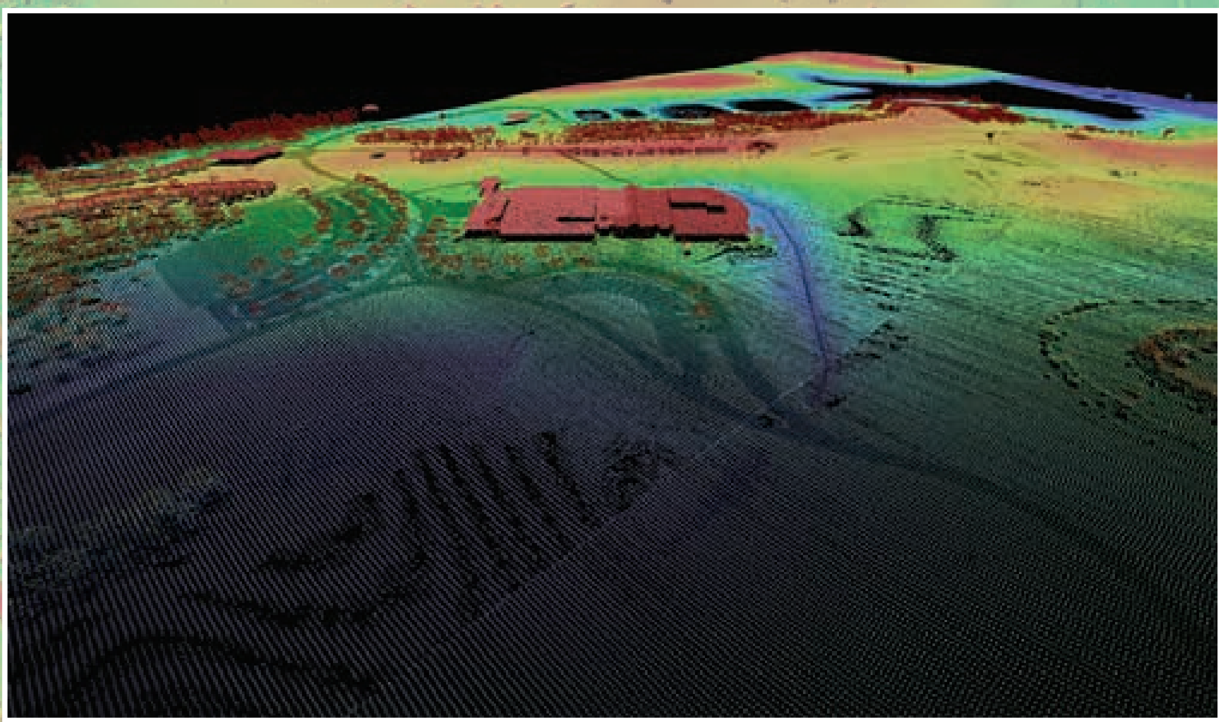
National Geospatial Program

Lidar Base Specification Version 1.0

Chapter 3 of
Section B, U.S. Geological Survey Standards
Book 11, Collection and Delineation of Spatial Data



Techniques and Methods 11–B3

U.S. Department of the Interior
U.S. Geological Survey

Cover. Background: Image depicts a hillshade first-return lidar surface of a suburban area of Sioux Falls, South Dakota.
Front cover inset: Image depicts a perspective view of an all-return lidar point cloud.
Back cover inset: Image depicts a hillshade perspective view of a hydro-flattened bare-earth lidar surface of Palisades State Park in Garretson, South Dakota.

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By Hans Karl Heidemann

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

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Suggested citation:
Heidemann, Hans Karl, 2012, Lidar base specification version 1.0, U.S. Geological Survey Techniques and Methods, book 11, chap. B3, 63 p.

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Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	2.471	acre
hectare (ha)	0.003861	square mile (mi^2) = 640 acres = 1 section
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861022	square mile (mi^2)

Altitude and Elevation, as used in this report, refers to the distance above the geoid, unless specifically referenced to the ellipsoid.

Height, as used in this report, refers to the height above ground.

Abbreviations and Acronyms

ARRA	American Reinvestment and Recovery Act
ASPRS	American Society for Photogrammetry and Remote Sensing
CLICK	Center for Lidar Information, Coordination, and Knowledge
CONUS	Conterminous United States
CORS	Continuously Operating Reference Stations
CVA	Consolidated Vertical Accuracy
DEM	Digital Elevation Model
DSM	Digital Surface Models
DTED	digital terrain elevation data
DTM	digital terrain model
EDNA	Elevation Derivatives for National Applications
EPSG	European Petroleum Survey Group
FGDC	Federal Geographic Data Committee
FOV	field of view
FVA	Fundamental Vertical Accuracy
GB	gigabyte
GPS	Global Positioning System
GSD	ground sample distance
H&H	hydraulic and hydrologic
IFSAR	Interferometric Synthetic Aperature Radar
lidar	light detection and ranging
IMU	Inertial Measurement Unit
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NDEP	National Digital Elevation Program
NED	National Elevation Dataset
NGP	National Geospatial Program
NGS	National Geodetic Survey
NIR	near infra-red
NIST	National Institute of Standards and Technology
NPS	Nominal Pulse Spacing
NSRS	National Spatial Reference System
NSSDA	National Standards for Spatial Data Accuracy
OCONUS	Outside the Conterminous United States
QA/QC	Quality Assurance/Quality Control
RMSE	Root Mean Square Error
SVA	Supplemental Vertical Accuracy
TIN	Triangulated Irregular Network
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
XML	eXtensible Markup Language

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Introductory Material

Purpose and Scope

The U.S. Geological Survey (USGS) intends to use this specification to acquire and procure light detection and ranging (lidar) data, and to create consistency across all USGS National Geospatial Program (NGP) and partner funded lidar collections, in particular those undertaken in support of the National Elevation Dataset (NED) (Gesch, 2007). Unlike most other "lidar data procurement specifications", which are focused on the products derived from lidar point cloud data; such as the bare-earth Digital Elevation Model (DEM), this specification places unprecedented emphasis on the handling of the source lidar point cloud data. The goal of this document is to assure that the complete acquired source dataset, including the data, metadata, descriptive documentation, quality information, and ancillary data—collected in accordance with the minimum parameters specified within—remains intact and viable to support the wide variety of DEM and non-DEM science and mapping applications that benefit from lidar technology. In the absence of other comprehensive specifications or standards, the USGS NGP hopes that this specification will, to the greatest degree practical, be adopted by other USGS programs and disciplines, and by other federal agencies.

Adherence to the following minimum specifications ensures that bare-earth DEMs derived from lidar data are suitable for ingestion into the NED at the 1/9 arc-second resolution, and can be resampled for use in the 1/3 and 1 arc-second NED resolutions. It also ensures that the point cloud source data are handled in a consistent manner by all data providers and delivered to the USGS in clearly defined formats. This allows straight-forward ingestion into lidar data management systems such as the Center for Lidar Information, Coordination, and Knowledge (CLICK) (Stoker and others, 2006) and simplifies subsequent use of the source data by the broader user community, particularly with regard to cross-collection analysis.

It must be emphasized that this is a base specification, defining minimum parameters for acceptance of the acquired lidar data. It is expected that local conditions in any given project area, specialized applications for the data, or the preferences of cooperators, may mandate more stringent requirements. The USGS encourages the collection of more detailed, accurate, or value-added data. A list of common upgrades to the minimum requirements defined in this report is provided in appendix 1.

Although lidar data have been used in the research and commercial mapping environments for more than a decade, it is still a relatively new technology. Advancements and improvements in instrumentation, software, processes, applications, and understanding are constantly refined or developed. It would not be possible to develop a set of guidelines and specifications that address all of these advances. The current document is based on the NGP's understanding of and experience with the lidar technology being used in the industry at the present time (2012). Furthermore, the NGP acknowledges that there is a lack of commonly accepted best practices for numerous processes and technical assessments (for example, measurement of Nominal Pulse Spacing (NPS), point distribution, classification accuracy, common accuracy and quality indicators, and others). The USGS encourages the development of such best practices through its partners in the industry, other Government agencies, and the appropriate professional governance organizations, and considers them for future revisions to this and other similar documents.

Applicability

These specifications and guidelines are applicable to lidar data and deliverables supported in whole or in part, with either financial or in-kind contributions, by the USGS NGP.

Maintenance Authority

The USGS NGP is the maintenance authority for this document.

Background

The USGS NGP has cooperated in the collection of numerous lidar datasets across the Nation for a wide array of applications. These collections used a variety of specifications and had a diverse set of product deliverables, resulting in incompatible datasets and making cross-project analysis extremely difficult. The need for a single base specification, defining minimum collection parameters and a consistent set of deliverables, is apparent.

Beginning in late 2009, an increase in the rate of lidar data collection because of the American Reinvestment and Recovery Act (ARRA) funding for *The National Map* made it imperative that a single data specification be implemented to ensure consistency and improve data utility. Although the development of this specification was prompted by the ARRA funding, the specification is intended to remain durable beyond ARRA-funded NGP projects.

In addition, it is recognized that the USGS NGP also uses lidar technology for specialized scientific research and other projects whose requirements are incompatible with the provisions of this specification. In such cases, and with properly documented justification supporting the need for the variance, waivers of any part or all of this specification may be granted.

It is conceivable that in some cases, based on specific topography, land cover, intended application, or other factors, the USGS-NGP may require specifications more rigorous than those defined in this document.

Technical alternatives to enhance delivery of data or associated products and processes as described by parameters and language in this document are encouraged and may be submitted with any proposal and will be given due professional consideration.

Collection

Multiple Discrete Returns

Data collection must be capable of at least three returns per pulse. Full waveform collection is acceptable and welcomed; however, waveform data are regarded as supplemental information. Deriving and delivering multiple discrete returns is required in all cases.

Intensity Values

Intensity values are required for each return. The values are to be recorded in the .las files in their native radiometric resolution.

Nominal Pulse Spacing (NPS)

An NPS of 2 meters or less is required. Dependent on the local terrain and land cover conditions in the project area, a greater point density may be required on specific projects. Assessment of the NPS will be made against single swath, first-return only data, located within the geometrically usable center portion (typically 90 percent) of each swath, acceptable data voids excluded. NPS will be calculated as the square root of the average area per point. Average along-track and cross-track point spacing should be comparable (within 10 percent).

In general, the target NPS for a project should not be achieved through swath overlap or multiple passes. Such collection techniques may be permitted with prior approval.

Data Voids

Data voids within a single swath are not acceptable, except in the following circumstances:

- Where caused by water bodies,

- Where caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing, or
- Where appropriately filled-in by another swath.

Spatial Distribution

The spatial distribution of geometrically usable points is expected to be uniform. Although it is understood that lidar instruments do not produce regularly gridded points, collections should be planned and executed to produce a first-return point cloud that approaches a regular lattice of points, rather than a collection of widely spaced high density profiles of the terrain. The uniformity of the point density throughout the dataset is important and will be assessed using the following steps:

- Generating a density grid from the data with cell sizes equal to the design NPS times 2, using a radius equal to the design NPS.
- Ensuring at least 90 percent of the cells in the grid contain at least one lidar point.
- The assessment is to be made against individual (single) swaths, using only the first-return points located within the geometrically usable center portion (typically 90 percent) of each swath.
- Excluding acceptable data voids previously identified in this specification.

Note: This requirement may be relaxed in areas of substantial relief where it is impractical to maintain a consistent and uniform distribution.

Note: The process described in this section relates only to the uniformity of the point distribution. It in no way relates to, nor can it be used for the assessment of point density or NPS.

Scan Angle

Scan angle will support horizontal and vertical accuracy within the requirements as specified in the next two sections. See Appendix 2 for additional information.

Note: This requirement primarily is applicable to oscillating mirror lidar systems. Other instrument technologies may be exempt from this requirement.

Vertical Accuracy

Vertical accuracy of the lidar data will be assessed and reported in accordance with the guidelines developed by the National Digital Elevation Program (NDEP) and subsequently adopted by the American Society for Photogrammetry and Remote Sensing (ASPRS). Complete definitions for vertical accuracy assessments are in Section 1.5 of the NDEP Elevation Guidelines (NDEP, 2004).

The minimum vertical accuracy requirement for the unclassified lidar point cloud, using the NDEP/ASPRS methodology, is listed below:

- Fundamental Vertical Accuracy (FVA)<= 24.5 centimeters (cm) Accuracyz (ACC_z), 95 percent (12.5 cm Root Mean Square Error $(RMSE)_z$).

The minimum vertical accuracy requirements for the derived DEM, using the NDEP/ASPRS methodology are listed below:

- Fundamental Vertical Accuracy (FVA)<= 24.5 cm ACC_z, 95 percent (12.5cm $RMSE_z$);
- Consolidated Vertical Accuracy (CVA)<= 36.3cm, 95th percentile, and
- Supplemental Vertical Accuracy (SVA)<= 36.3 cm, 95th percentile.

Point cloud data accuracy is to be tested against a Triangulated Irregular Network (TIN) constructed from lidar points in clear and open areas. A clear and open area can be characterized with respect to topographic and ground cover variation such that a minimum of 5 times the NPS exists with less than 1/3 of the $RMSE_z$ deviation from a low-slope plane. Slopes that exceed 10 percent should be avoided. Ground that has been plowed or otherwise disturbed is not acceptable. All tested locations should be photographed showing the position of the tripod and the surrounding area ground condition.

Each land cover type representing 10 percent or more of the total project area must be tested and reported with an SVA. In areas where a land cover category is something other than forested or dense urban, the tested point should not have any obstructions 45 degrees above the horizon to ensure a sufficient TIN surface. Additionally, tested areas should not be in proximity to low NIR reflective surfaces such as asphalt or composition roofing materials.

The SVA value is provided as a target. It is understood that in areas of dense vegetation, swamps, or extremely difficult terrain, this value may be exceeded.

The CVA value is a requirement that must be met, regardless of any allowed "busts" in the SVA(s) for individual land cover types within the project.

Checkpoints for each assessment (FVA, CVA, and all SVAs) are required to be well-distributed throughout the land cover type, for the entire project area. See Glossary for definition of well-distributed.

Exceptions: These requirements may be relaxed in cases:

- Where there exists a demonstrable and substantial increase in cost to obtain this accuracy.
- Where an alternate specification is needed to conform to previously contracted phases of a single larger overall collection effort, for example, multi-year statewide collections.
- Where the USGS agrees that it is reasonable and in the best interest of all stakeholders to use an alternate specification.

Relative Accuracy

The requirements for relative accuracy are listed below:

- Within individual swaths:<= 7 cm $RMSE_z$
- Within overlap between adjacent swaths:<=10 cm $RMSE_z$

Flightline Overlap

Flightline overlap of 10 percent or greater is required to ensure there are no data gaps between the usable portions of the swaths. Collections in high relief terrain are expected to require greater overlap. Any data with gaps between the geometrically usable portions of the swaths will be rejected.

Collection Area

Data collection for the Defined Project Area, buffered by a minimum of 100 meters, is required. The buffered boundary is the Buffered Project Area.

In order that all products are consistent to the edge of the Defined Project Area, all products must be generated to the limit of the Buffered Project Area. Since these areas are being generated, they shall also be delivered.

Collection Conditions

Atmospheric conditions must be cloud and fog-free between the aircraft and ground during all collection operations.

Ground conditions must be snow free. Very light, undrifted snow may be acceptable in special cases, with prior approval.

Water conditions must be free of any unusual flooding or inundation, except in cases where the goal of the collection is to map the inundation.

Leaf-off vegetation conditions are preferred, however, as numerous factors beyond human control may affect the vegetative condition at the time of any collection, the USGS NGP only requires that penetration to the ground must be adequate to produce an accurate and reliable bare-earth surface suitable for incorporation into the 1/9 (3-meter) NED. Collections for specific scientific research projects may be exempted from this requirement, with prior approval.

Data Processing and Handling

ASPRS LAS File Format

All processing should be carried out with the understanding that all point deliverables are required to be in fully compliant LAS format, either v1.2 or v1.3. The version selected must be used for all LAS deliverables in the project. Data producers are encouraged to review the LAS specification in detail (ASPRS, 2011).

Full Waveform

If full waveform data are collected, delivery of the waveform packets is required. LAS v1.3 deliverables with waveform data are to use external auxiliary files with the extension .wdp for the storage of waveform packet data. See the LAS v1.3 Specification for additional information (ASPRS, 2011).

Global Positioning System (GPS) Times

GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse. Adjusted GPS Time is defined to be Standard (or satellite) GPS time minus $1*10^9$. See the LAS v1.3 Specification for more detail (ASPRS, 2011).

Datums

All data collected must be tied to the datums listed below:

- Horizontal datum reference to the North American Datum of 1983/HARN adjustment (NAD83 HARN) is required.
- Vertical datum reference to the North American Vertical Datum of 1988 (NAVD 88) is required.
- The most recent National Geodetic Survey (NGS)-approved geoid model is required to perform conversions from ellipsoidal heights to orthometric heights.

Coordinate Reference System

The USGS preferred Coordinate Reference System for the Conterminous United States (CONUS) is Universal Transverse Mercator UTM, NAD83 HARN, Meters; NAVD88, Meters. Each discrete project is to be processed using the single predominant UTM zone for the overall collection area.

The USGS will also accept data in other Coordinate Reference Systems that meet the conditions below:

- State Plane and State Coordinate Reference Systems that have been accepted by the European Petroleum Survey Group (EPSG) may be used.
- Coordinate Reference Systems for collections in Alaska, Hawaii, and other areas Outside the Conterminous United States (OCONUS) must be approved by the USGS before collection.

Units of Reference

All references to the unit of measure “Feet” and “Foot” must specify “International”, “Intl”, “U.S. Survey”, or “US”.

Swath Identification

Each swath will be assigned a unique File Source ID. It is required that the Point Source ID field for each point within each LAS swath file be set equal to the File Source ID before any processing of the data. See the LAS v1.3 Specification (ASPRS, 2011).

Point Families

Point families (multiple return “children” of a single “parent” pulse) shall be maintained intact through all processing before tiling. Multiple returns from a given pulse will be stored in sequential (collected) order.

Swath Size and Segmentation

Swath files will be 2 gigabytes (GB) in size or less. Long swaths (those which result in a LAS file larger than 2 GB) will be split into segments no greater than 2 GB each.

- Each sub-swath will retain the original File Source ID of the original complete swath.
- Points within each sub-swath will retain the Point Source ID of the original complete swath.
- Each sub-swath file will be named identically to the original complete swath, with the addition of an ordered alphabetic suffix to the name (“-a”, “-b” … “-n”). The order of the named sub-swaths shall be consistent with the collection order of the points (“-a” will be the chronological beginning of the swath; “-n” will be the chronological end of the swath).
- Point families shall be maintained intact within each sub-swath.
- Sub-swaths should be broken at the edge of the scan line.
- Other swath segmentation approaches may be acceptable, with prior approval.

Scope of Collection

All collected swaths are to be delivered as part of the Raw Data Deliverable. This includes calibration swaths and cross-ties. This in no way requires or implies that calibration swath data are to be included in product generation. All collected points are to be delivered. No points are to be deleted from the swath LAS files. Excepted from this are extraneous data outside of the buffered project area (aircraft turns, transit between the collection area and airport, transit between fill-in areas, and the like). These points may be permanently removed. Busted swaths that are being completely discarded by the vendor and re-flown do not need to be delivered.

Use of the LAS Withheld Flag

Outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath, and other points the vendor deems unusable are to be identified using the Withheld flag, as defined in the LAS specification.

This applies primarily to points that are identified during pre-processing or through automated post-processing routines.

If processing software is not capable of populating the Withheld bit, these points may be identified using Class=11.

Noise points subsequently identified during manual Classification and Quality Assurance/Quality Control (QA/QC) may be assigned the standard LAS classification value for Noise (Class=7), regardless of whether the noise is “low” or “high” relative to the ground surface.

Point Classification

- ALL points not identified as Withheld are to be classified.
- No points in the Classified LAS deliverable will be assigned Class=0.
- Use of the ASPRS/LAS Overlap classification (Class=12) is prohibited.

If overlap points are required to be differentiated by the data producer or cooperating partner, they must be identified using a method that does not interfere with their classification:

- Overlap points are tagged using Bit:0 of the User Data byte, as defined in the LAS specification. (SET=Overlap).
- Overlap points are classified using the Standard Class values + 16.

- Other techniques as agreed upon in advance.

The technique used to identify overlap must be clearly described in the project metadata files.

Note: A standard bit flag for identification of overlap points has been included in LAS v1.4, released on November 14, 2011.

Positional Accuracy Validation

Before classification of and development of derivative products from the point cloud, verification of the vertical accuracy of the point cloud, absolute and relative, is required. The Fundamental Vertical Accuracy (absolute) is to be assessed in clear, open areas as described in the section called Vertical Accuracy above. Swath-to-swath and within swath accuracies (relative) are to be documented. A detailed report of this validation process is a required deliverable.

Classification Accuracy

It is required that due diligence in the classification process will produce data that meet the following tests:

- Following classification processing, no non-withheld points should remain in Class 0.
- Within any 1 kilometer (km) x 1 km area, no more than 2 percent of non-withheld points will possess a demonstrably erroneous classification value.
- Points remaining in Class 1 that should be classified in any other required Class are subject to these accuracy requirements and will be counted towards the 2 percent threshold.

Note: These requirements may be relaxed to accommodate collections in areas where the USGS agrees classification to be particularly difficult.

Classification Consistency

Point classification is to be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, lifts, or other non-natural divisions will be cause for rejection of the entire deliverable.

Tiles

Note: This section assumes a projected coordinate reference system.

A single non-overlapped tiling scheme (the Project Tiling Scheme) will be established and agreed upon by the data producer and the USGS before collection. This scheme will be used for ALL tiled deliverables.

- Tile size is required to be an integer multiple of the cell size of raster deliverables.
- Tiles are required to be sized using the same units as the coordinate system of the data.
- Tiles are required to be indexed in X and Y to an integer multiple of the tile's X-Y dimensions.
- All tiled deliverables will conform to the Project Tiling Scheme, without added overlap.
- Tiled deliverables will edge-match seamlessly and without gaps.

Hydro-Flattening

Note: Please refer to appendix 3 for reference information on hydro-flattening.

Hydro-flattening pertains only to the creation of derived DEMs. No manipulation of or changes to originally computed lidar point elevations are to be made. Breaklines may be used to help classify the point data. The goal of the NGP is for the delivered DEMs to represent water bodies in a cartographically and aesthetically pleasing manner. It is not the goal of the NGP to accurately map water surface elevations within the NED. The requirements for hydro-flattening are listed below.

Inland Ponds and Lakes

- 2 acres or greater surface area (approximately equal to a round pond 350 feet in diameter) 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. The presence of floating water bodies will be cause for rejection of the deliverable.
- Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, are required to be treated as rivers.

Inland Streams and Rivers

- 100 feet nominal width: This should not unnecessarily break a stream or river into multiple segments. At times it may squeeze slightly below 100 feet for short segments. Data producers should use their best professional cartographic judgment.
- Flat and level bank-to-bank (perpendicular to the apparent flow centerline); gradient to follow the immediately surrounding terrain. In cases of sharp turns of rapidly moving water, where the natural water surface is notably not level bank-to-bank, it is appropriate to represent the water surface as it exists in nature, while maintaining an aesthetic cartographic appearance.
- The entire water surface edge must be at or below the immediately surrounding terrain.
- Stream channels are required to break at road crossings (culvert locations). The roadway over a culvert should be continuous. A culvert, regardless of size, is defined as having earth between the road surface and the top of the structure.
- Bridges are required to be removed from the DEM. Streams and rivers should be continuous at bridge locations. Bridges are defined as having an elevated deck structure that does not rest on earth.
- When the identification of a structure such as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.

Non-Tidal Boundary Waters

- Represented only as an edge or edges within the project area; collection does not include the opposing shore.
- Water surface is to be flat and level, as appropriate for the type of water body (level for lakes; gradient for rivers)
- The entire water surface edge must be at or below the immediately surrounding terrain.

Tidal Waters

- Tidal water bodies are defined as water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, large lakes, and the like. This includes any water body that is affected by tidal variations.
- Tidal variations over the course of a collection or between different collections, will result in lateral and vertical discontinuities along shorelines. This is considered normal and these anomalies should be retained. The final DEM is required to represent as much ground as the collected data permits.
- Water surface is to be flat and level, to the degree allowed by the irregularities noted above.
- Scientific research projects in coastal areas often have specific requirements with regard to how tidal land-water boundaries are to be handled. For such projects, the requirements of the research will take precedence.

Islands

- Permanent islands 1 acre or larger shall be delineated within all water bodies.

Single-Line Streams

Cooperating partners may require collection and integration of single-line streams within their lidar projects. Although the USGS does not require these breaklines be collected or integrated, it does require that if used and incorporated into the DEMs, the following guidelines are met:

- All vertices along single-line stream breaklines are at or below the immediately surrounding terrain.
- Single-line stream breaklines are not to be used to introduce cuts into the DEM at road crossings (culverts), dams, or other such features. This is hydro-enforcement and as discussed in appendix 3 will create a non-topographic DEM that is unsuitable for integration into the NED.
- All breaklines used to modify the surface are to be delivered to the USGS with the DEMs.

Deliverables

The USGS requires unrestricted rights to all delivered data and reports, which will be placed in the public domain. This specification places no restrictions on the data provider's rights to resell data or derivative products as they see fit.

Metadata

The term "metadata" refers to all descriptive information about the project. This includes textual reports, graphics, supporting shapefiles, and Federal Geographic Data Committee (FGDC)-compliant metadata files. Metadata deliverables include the following items:

- Collection report detailing mission planning and flight logs.
- Survey report detailing the collection of control and reference points used for calibration and QA/QC.
- Processing report detailing calibration, classification, and product generation procedures including methodology used for breakline collection and hydro-flattening (see the section called Hydro-Flattening and appendix 3 for more information on hydro-flattening).
- QA/QC Reports (detailing the analysis, accuracy assessment and validation of the following:
  - Point data (absolute, within swath, and between swath)
  - Bare-earth surface (absolute)
  - Other optional deliverables as appropriate
- Control and calibration points: All control and reference points used to calibrate, control, process, and validate the lidar point data or any derivative products that are to be delivered.
- Georeferenced, digital spatial representation of the precise extents of each delivered dataset. This should reflect the extents of the actual lidar source or derived product data, exclusive of TIN artifacts or raster NODATA areas. A union of tile boundaries or minimum bounding rectangles is not acceptable. ESRI Polygon shapefile or geodatabase is preferred.
- Product metadata [FGDC compliant, eXtensible Markup Language (XML) format metadata]. Metadata files for individual files are not required. One XML file is required for the following examples:
  - The Overall Project: Describing the project boundary, the intent of the project, the types of data collected as part of the project, the various deliverables for the project, and other project-wide information.

- Each Lift: Describing the extents of the lift, the swaths included in the lift, locations of GPS base stations and control for the lift, preprocessing and calibration details for the lift, adjustment and fitting processes applied to the lift in relation to other lifts, and other lift-specific information.
- Each tiled deliverable product group:
  - Classified point data
  - Bare-earth DEMs
  - Breaklines (if used)
  - Other datasets delivered under the contract (Digital Surface Models (DSM), intensity images, height surfaces, and others)
- FGDC compliant metadata must pass the USGS metadata parser (mp) with no errors.

Note: Please refer to the metadata templates in appendixes 4 and 5 for additional information.

Raw Point Cloud

Delivery of the raw point cloud is a standard requirement for USGS NGP lidar projects. Raw point cloud deliverables include the following items:

- All swaths, returns, and collected points, fully calibrated and adjusted to ground, by swath.
- Fully compliant LAS v1.2 or v1.3, Point Data Record Format 1, 3, 4, or 5.
- LAS v1.3 deliverables with waveform data are to use external auxiliary files with the extension .wdp for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
- Correct and properly formatted georeference information must be included in all LAS file headers.
- GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse.
- Intensity values (native radiometric resolution).
- One file per swath, one swath per file, file size not to exceed 2 GB, as described under the section called Swath Size and Segmentation above.
- Vertical accuracy of the lidar point data will be assessed and reported in accordance with the guidelines developed by the NDEP and subsequently adopted by the ASPRS. The complete guidelines on vertical accuracy are in Section 1.5 of the NDEP Guidelines (NDEP, 2004).
- Vertical accuracy requirements using the NDEP/ASPRS methodology for the point cloud are FVA<= 24.5 cm ACC_z, 95-percent confidence level (12.5 cm $RMSE_z$)

Classified Point Cloud

Delivery of a classified point cloud is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement. Classified point cloud deliverables include the following items:

- All project swaths, returns, and collected points, fully calibrated, adjusted to ground, and classified, by tiles. Project swaths exclude calibration swaths, cross-ties, and other swaths not used, or intended to be used, in product generation.
- Fully compliant LAS v1.2 or v1.3, Point Data Record Format 1, 3, 4, or 5.
- LAS v1.3 deliverables with waveform data are to use external auxiliary files with the extension .wdp for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
- Correct and properly formatted georeference information must be included in all LAS file headers.
- GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse.

- Intensity values (native radiometric resolution).
- Tiled delivery, without overlap, using Project Tiling Scheme.
- Classification Scheme (minimum) as listed in table 1.

Bare-Earth Surface (Raster DEM)

Delivery of a bare-earth DEM is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement. Bare-earth surface deliverables include the following items:

- Bare-earth DEM, generated to the limits of the Buffered Project Area.
- Cell size no greater than 3 meters or 10 feet, and no less than the design Nominal Pulse Spacing (NPS).
- Delivery in an industry-standard, GIS-compatible, 32-bit floating point raster format (ERDAS .IMG preferred).

Table 1. Minimum Classified Point Cloud Classification Scheme.

Code	Description
1	Processed, but unclassified
2	Bare-earth ground
7[a]	Noise (low or high; manually identified; if needed)
9	Water
10[b]	Ignored Ground (Breakline proximity)
11	Withheld (if the Withheld bit is not implemented in processing software)

[a]Class 7, Noise, is included as an adjunct to the Withheld bit. All noise points are to be identified using one of these two methods.

[b]Class 10, Ignored Ground, is for points previously classified as bare-earth but whose proximity to a subsequently added breakline requires that it be excluded during Digital Elevation Model (DEM) generation.

- Georeference information shall be included in each raster file.
- Tiled delivery, without overlap.
- DEM tiles will show no edge artifacts or mismatch. A quilted appearance in the overall project DEM surface, whether caused by differences in processing quality or character between tiles, swaths, lifts, or other non-natural divisions, will be cause for rejection of the entire deliverable.
- Void areas (for example, areas outside the Buffered Project Area but within the tiling scheme) shall be coded using a unique NODATA value. This value shall be identified in the appropriate location within the raster file header or external support files (for example, .aux).
- Vertical accuracy of the bare-earth surface will be assessed and reported in accordance with the guidelines developed by the NDEP and subsequently adopted by the ASPRS. The complete guidelines are in Section 1.5 of the NDEP Guidelines (NDEP, 2004).
- The following threshholds represent the minimum vertical accuracy requirements using the NDEP/ASPRS methodology:
    - FVA<= 24.5 cm ACC_z, 95 percent Confidence Level (12.5 cm $RMSE_z$)
    - CVA<= 36.3 cm, 95th percentile
    - SVA<= 36.3 cm, 95th percentile
- All QA/QC analysis materials and results are to be delivered to the USGS.

- Depressions (sinks), natural or man-made, are not to be filled (as in hydro-conditioning and hydro-enforcement).
- Water bodies (ponds and lakes), wide streams and rivers (double-line), and other non-tidal water bodies as defined in the section called Hydro-flattening are to be hydro-flattened within the DEM. Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are larger than 2 acres in area (approximately equal to a round pond 350 feet in diameter), to all streams that are nominally wider than 100 feet, and to all non-tidal boundary waters bordering the project area regardless of size. The methodology used for hydro-flattening is at the discretion of the data producer.

Note: Please refer to the section called Hydro-Flattening and appendix 3 for detailed discussions of hydro-flattening.

Breaklines

Delivery of the breaklines used in hydro-flattening is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement. If hydro-flattening is achieved through other means, this section may not apply. Breakline deliverables include the following items:

- Breaklines shall be developed to the limit of the Buffered Project Area.
- All breaklines developed for use in hydro-flattening shall be delivered as an ESRI feature class (PolylineZ or PolygonZ format, as appropriate to the type of feature represented and the methodology used by the data producer). Shapefile or geodatabase is required.
- Each feature class or shapefile will include properly formatted and accurate georeference information in the standard location. All shapefiles must include a correct and properly formatted *.prj file.
- Breaklines must use the same coordinate reference system (horizontal and vertical) and units as the lidar point delivery.
- Breakline delivery may be as a continuous layer or in tiles, at the discretion of the data producer. In the case of tiled deliveries, all features must edge-match exactly across tile boundaries in both the horizontal (*X-Y*) and vertical (*Z*) spatial locations.

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Glossary

Note: Many of the following definitions are taken from Maune (2007) and are used with permission.

A

accuracy The closeness of an estimated value (for example, measured or computed) to a standard or accepted (true) value of a particular quantity. Note: With the exception of Continuously Operating Reference Stations (CORS), assumed to be known with zero errors relative to established datums, the true locations of 3-D spatial coordinates of other points are not truly known, but only estimated; therefore, the accuracy of other coordinate information is unknown and can only be estimated.

- **absolute accuracy** A measure that accounts for all systematic and random errors in a dataset. Absolute accuracy is stated with respect to a defined datum or reference system.
- **accuracy$_r$** (ACC_r) The National Standards for Spatial Data Accuracy (NSSDA) reporting standard in the horizontal component that equals the radius of a circle of uncertainty, such that the true or theoretical horizontal location of the point falls within that circle 95 percent of the time. ACCr = 1.7308 x Root Mean Square Error $(RMSE)_r$.
- **accuracy$_z$** (ACC_z) The NSSDA reporting standard in the vertical component that equals the linear uncertainty value, such that the true or theoretical vertical location of the point falls within that linear uncertainty value 95 percent of the time. ACC_z = 1.9600 x $RMSE_z$.
- **horizontal accuracy** The positional accuracy of a dataset with respect to a horizontal datum. The horizontal accuracy reporting standard (ACC_r) is defined above.
- **local accuracy** A value that represents the uncertainty in the coordinates of a control point relative to the coordinates of other directly connected, adjacent control points at the 95-percent confidence level. The reported local accuracy is an approximate average of the individual local accuracy values between this control point and other observed control points used to establish the coordinates of the control point.
- **network accuracy** A value that represents the uncertainty in the coordinates of a control point with respect to the geodetic datum at the 95-percent confidence level. For National Spatial Reference System (NSRS) network accuracy classification in the United States, the datum is considered to be best expressed by the geodetic values at the CORS supported by the National Geodetic Survey (NGS). By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, that is, to approach zero.
- **positional accuracy** The accuracy of the position of features, including horizontal and vertical positions.
- **relative accuracy** A measure that accounts for random errors in a dataset. Relative accuracy may also be referred to as point-to-point accuracy. The general measure of relative accuracy is an evaluation of the random errors (systematic errors and blunders removed) in determining the positional orientation (for example, distance, azimuth) of one point or feature with respect to another. In lidar, this also may specifically mean the accuracy between adjacent swaths within a lift, adjacent lifts within a project, or between adjacent projects.

- **vertical accuracy** The measure of the positional accuracy of a dataset with respect to a specified vertical datum. The vertical accuracy reporting standard (ACC_z) is defined above.

ambiguity resolution Combining the phase data from two or more Global Positioning System (GPS) receivers so that, after eliminating all other significant errors, the unknown number of integer wavelengths can be determined for signals coming from GPS satellites. Redundant L1 and L2 phase observations from two or more receivers, each tracking five or more satellites, provide the information for rapid unambiguous resolution. Once the ambiguities are resolved, the corrected phases for each observed satellite become precise ranges that allow the computation of the baseline vector(s) between the receivers with a typical accuracy of 2–10 centimeters.

artifacts An inaccurate observation, effect, or result, especially one resulting from the technology used in scientific investigation or from experimental error. In bare-earth elevation models, detectable surface remnants of buildings, trees, towers, telephone poles or other elevated features; also, detectable artificial anomalies that are introduced to a surface model by way of system specific collection or processing techniques, for example, corn-row effects of profile collection, star and ramp effects from multidirectional contour interpolation, or detectable triangular facets caused when vegetation canopies are removed from lidar data.

arc-second In angular measurements, 1/3600 of a degree. Commonly used in descriptions of geographic coordinate reference systems, for example, the horizontal resolution of the National Elevation Dataset (NED) (1 arc-second, 1/3 arc-second. 1/9 arc-second). For most of the Contiguous United States (CONUS), 1 arc-second is approximately 30 meters, linear.

aspect The direction which a building or topographic surface faces with respect to points of a compass. The slope direction or steepest downslope across a surface, normally measured clockwise in degrees from due north. The value of each location in an aspect dataset indicates the direction the surface slope faces.

attitude The position of a body defined by the angles between the axes of the coordinate system of the body and the axes of an external coordinate system. In photogrammetry, the attitude is the angular orientation of a camera (roll, pitch, yaw), or of the photograph taken with that camera, with respect to some external reference system. With lidar and Interferometric Synthetic Aperature Radar (IFSAR), the attitude is normally defined as the roll, pitch and heading of the instrument at the instant an active pulse is emitted from the sensor.

B

bald earth Non-preferred term. *See* bare earth.

bare earth (bare-earth) Digital elevation data of the terrain, free from vegetation, buildings and other man-made structures. Elevations of the ground.

boresight Calibration of a lidar sensor system equipped with an Inertial Measurement Unit (IMU) and Global Positioning System (GPS) to determine or establish the accurate:

- Position of the instrument (x, y, z) with respect to the GPS antenna
- Orientation (roll, pitch, heading) of the lidar instrument with respect to straight and level flight.

breakline A linear feature that describes a change in the smoothness or continuity of a surface. The two most common forms of breaklines are as follows:

- A **soft breakline** ensures that known z-values along a linear feature are maintained (for example, elevations along a pipeline, road centerline or drainage ditch), and ensures that linear features and polygon edges are maintained in a Triangulated Irregular Network (TIN) surface model, by enforcing the breaklines as TIN edges. They are generally synonymous with 3-D breaklines because they are depicted with series of x/y/z coordinates. Somewhat rounded ridges or the trough of a drain may be collected using soft breaklines.

- A **hard breakline** defines interruptions in surface smoothness, for example, to define streams, shorelines, dams, ridges, building footprints, and other locations with abrupt surface changes. Although some hard breaklines are 3-D breaklines, they are often depicted as 2-D breaklines because features such as shorelines and building footprints are normally depicted with series of X/Y coordinates only, often digitized from digital orthophotos that include no elevation data.

bridge A structure carrying a road, path, railroad, or canal across a river, ravine, road, railroad, or other obstacle. In mapping, this is distinguished from a roadway over a culvert, in that a bridge is a man-made elevated deck for which there is no earth or soil. *See* culvert.

C

calibration The process of identifying and correcting for systematic errors in hardware, software, or procedures. Determining the systematic errors in a measuring device by comparing its measurements with the markings or measurements of a device that is considered correct. Airborne sensors can be calibrated geometrically and radiometrically.

- **lidar system calibration** Falls into two main categories:
  - **instrument calibration** Factory calibration includes radiometric and geometric calibration unique to each manufacturer's hardware, and tuned to meet the performance specifications for the model being calibrated. Instrument calibration can only be assessed and corrected by the factory.
  - **data calibration** The lever-arm calibration determines the sensor-to-GPS-antenna offset vector (lever arm) components relative to the antenna phase center; the offset vector components are re-determined each time the sensor or aircraft GPS antenna is moved or repositioned in any way. Because normal aircraft operations can induce slight variations in component mounting, field calibration is normally performed for each project, or even daily, to determine corrections to the roll, pitch, yaw, and scale calibration parameters.

check point (checkpoint) One of the surveyed points used to estimate the positional accuracy of a geospatial dataset against an independent source of greater accuracy.

classification (of lidar) The classification of lidar point cloud returns in accordance with a classification scheme to identify the type of target from which each lidar return is reflected. The process allows future differentiation between bare-earth terrain points, water, noise, vegetation, buildings, other manmade features and objects of interest.

cleanness A subjective term to describe the degree to which artifacts have been removed from a Digital Elevation Model (DEM) or Triangulated Irregular Network (TIN).

confidence level The probability that errors are within a range of given values.

consolidated vertical accuracy (CVA) The result of a test of the accuracy of a lidar digital terrain model using 3-D Quality Assurance/Quality Control (QA/QC) checkpoints in multiple land cover categories combined, normally including open terrain and vegetated terrain representative of the land cover for the area being tested. Computed using a nonparametric testing method (95th percentile), a consolidated vertical accuracy is always accompanied by a fundamental vertical accuracy. *See* percentile.

CONUS Continental United States; the contiguous 48 states.

culvert A tunnel carrying a stream or open drain under a road or railroad. Typically constructed of formed concrete or corrugated metal and surrounded on all sides, top, and bottom by earth or soil.

D

data void In lidar, a gap in the point cloud coverage, caused by surface non-reflectance of the lidar pulse, instrument or processing anomalies or failure, obstruction of the lidar pulse, or improper collection flight planning. Any area greater than or equal to (4 times the Nominal

Pulse Spacing (NPS)) squared, measured using first-returns only, is considered to be a data void. *See* holiday.

datum A set of reference points on the Earth's surface against which position measurements are made, and (often) an associated model of the shape of the earth (reference ellipsoid) to define a geographic coordinate system. Horizontal datums (for example, the North American Datum of 1983 (NAD83)) are used for describing a point on the earth's surface, in latitude and longitude or another coordinate system. Vertical datums (for example, the North American Vertical Datum of 1988 (NAVD88)) measure elevations or depths. In engineering and drafting, a datum is a reference point, surface, or axis on an object against which measurements are made.

digital elevation model (DEM) *See* four different definitions below:

- A popular acronym used as a generic term for digital topographic and bathymetric data in all its various forms. Unless specifically referenced as a Digital Surface Model (DSM), the generic DEM normally implies x/y coordinates and z-values of the bare-earth terrain, void of vegetation and manmade features.
- As used by the U.S. Geological Survey (USGS), a DEM is the digital cartographic representation of the elevation of the land at regularly spaced intervals in x and y directions, using z-values referenced to a common vertical datum.
- As typically used in the United States and elsewhere, a DEM has bare-earth z-values at regularly spaced intervals in x and y directions; however, grid spacing, datum, coordinate systems, data formats, and other characteristics may vary widely.
- A "D-E-M" is a specific raster data format once widely used by the USGS. DEMs are a sampled array of elevations for a number of ground positions at regularly spaced intervals.

digital surface model (DSM) Similar to Digital Elevation Models (DEMs) or digital terrain models (DTMs), except that they may depict the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare earth. DSMs are especially relevant for telecommunications management, air safety, forest management, and 3-D modeling and simulation.

digital terrain elevation data (DTED) A uniform matrix of terrain elevation values produced by the National Geospatial-Intelligence Agency (NGA). It provides basic quantitative data for military systems that require terrain elevation, slope, and gross surface roughness information. Data density depends on the level produced.

- DTED0 post spacing is 30-arc seconds (approximately 1,000 meters), corresponding to small-scale hardcopy products.
- DTED1 post spacing is 3-arc seconds (approximately 100 meters), corresponding to medium-scale hardcopy products.
- DTED2 post spacing is 1-arc second (approximately 30 meters), corresponding to large-scale hardcopy products.
- Specifications for high-resolution DTED levels 3 (10 m), 4 (3 m), and 5 (1 m) also may been developed.

digital terrain model (DTM) *See* two different definitions below:

- In some countries, DTMs are synonymous with Digital Elevation Models (DEMs), representing the bare-earth terrain with uniformly-spaced z-values.
- As used in the United States, DTMs may be similar to DEMs, but they may also incorporate the elevation of important topographic features on the land. DTMs are comprised of mass points and breaklines that are irregularly spaced to better characterize the true shape of the bare-earth terrain. The net result of DTMs is that the distinctive terrain features are more clearly defined and precisely located, and contours generated from

DTMs more closely approximate the real shape of the terrain. Such DTMs are normally more expensive and time consuming to produce than uniformly spaced DEMs because breaklines are less suitable for automated collection; but the DTM may be technically superior to standard DEMs for many applications. DTMs are most commonly associated with ground surface models derived using stereo photogrammetry, as opposed to lidar.

discrete return lidar Lidar system or data in which the significant peaks in the waveform are captured and stored. Each peak represents a return from a different target, discernible in either vertical or horizontal domains. Most modern lidar systems are capable of capturing multiple discrete returns from each emitted laser pulse. *See* full waveform lidar.

drape The superposition of 2-D features over a 3-D surface, normally for viewing of all features in 3-D perspective, for 3-D fly-throughs or walk-throughs in virtual reality. Also a method for conflating values, typically elevation, from a surface to 2D features to create 3D features.

E

elevation The distance measured upward along a plumb line between a point and the geoid. The elevation of a point is normally the same as its orthometric height, defined as H in the equation:

$$H = h - N, \text{ where } h = \text{ellipsoid height and } N = \text{geoid height.}$$

elevation post The vertical component of a Digital Elevation Model (DEM) lattice mesh point, having height above the vertical datum equal to the z-value of its mesh point.

elevation post spacing The constant sampling interval in x and y directions of a Digital Elevation Model (DEM) lattice. The horizontal resolution of a DEM.

F

field of view (FOV), lidar The angular extent of the portion of object space surveyed by a lidar sensor, measured in degrees. To avoid confusion, a typical airborne lidar sensor with a field of view of 30 degrees is commonly depicted as ±15 degrees on either side of nadir.

first return (first-return) The first significant measurable portion of a return lidar pulse.

flightline A single pass of the collection aircraft over the target area. Often used incorrectly to refer to the data resulting from a flightline of collection. *See* swath.

full waveform lidar Lidar system or data in which the entire reflection of the laser pulse is fully digitized, captured, and stored. Discrete return point clouds can be extracted from the waveform data during post processing. *See* discrete return lidar.

fundamental vertical accuracy (FVA) The value by which vertical accuracy of lidar can be equitably assessed and compared among datasets. The fundamental vertical accuracy of a dataset must be determined with well-distributed checkpoints located only in open terrain, free of vegetation, where there is a high probability that the sensor will have detected the ground surface. It is obtained using standard tests for Root Mean Square Error (RMSE), where $FVA = ACC_z = RMSE_z \times 1.9600$.

G

geographic information system (GIS) A system of spatially referenced information, including computer programs that acquire, store, manipulate, analyze, and display spatial data.

geospatial data Information that identifies the geographic location and characteristics of natural or constructed features and boundaries of earth. This information may be derived from, among other things, remote-sensing, mapping, and surveying technologies. Geospatial data generally are considered to be synonymous with spatial data; however, the former always is associated with geographic or cartesian coordinates linked to a horizontal or vertical datum, whereas the latter (for example, generic architectural house plans) may include dimensions and other spatial data not linked to any physical location.

grid post *See* elevation post.

ground sample distance (GSD) The size of a pixel projected to the ground surface, reported as linear units/pixel, such as 1 meter/pixel or 1 foot/pixel. Actual or nominal distance in ground measurements between ground elevation samples. Different from horizontal post spacing in that *horizontal post spacing* describes the ground-distance interval of a uniform elevation grid, whereas *ground sample distance* describes the spacing on the ground of the source data. For example, the ground distance between data points collected by a lidar system, although variable, will yield some nominal *ground sample distance*. A gridded data model produced by resampling the lidar data may be incremented on a different, user-selected *horizontal post spacing*.

ground truth Verification of a situation, without errors introduced by sensors or human perception and judgment.

H

hillshade A function used to create an illuminated representation of the surface, using a hypothetical light source, to enhance terrain visualization effects.

holiday An area of missing coverage, caused by missing or unresolvable data, data edits, or incorrectly positioned flightlines, normally identified for further investigation or re-flying. An unintentionally unsurveyed part of a region that was to have been completely surveyed. *See* data void.

horizontal accuracy Positional accuracy of a dataset with respect to a horizontal datum. According to the National Standards for Spatial Data Accuracy (NSSDA), horizontal (radial) accuracy at the 95-percent confidence level is defined as Accuracyr (ACCr).

horizontal post spacing The ground distance interval between grid posts in a uniformly gridded data model. It is important to note that features of a size equal to, or even greater than the post spacing, may not be detected or explicitly represented in a gridded model. For gridded elevation data, the horizontal post spacing may be referenced as the cell size, the grid spacing, the posting interval, or the ground sample distance.

hydraulic modeling The use of digital elevation data, rainfall runoff data from hydrologic models, surface roughness data, and information on hydraulic structures (for example, bridges, culverts, dams, weirs, sewers) to predict flood levels and manage water resources. Hydraulic models are based on computations involving liquids under pressure, and there are many other definitions of hydraulic modeling that have nothing to do with terrain elevations, for example, modeling of hydraulic lines in aircraft and automobiles.

hydrologic modeling The computer modeling of rainfall and the effects of land cover, soil conditions, and terrain slope to estimate rainfall runoff into streams and lakes. Digital elevation data are used as part of hydrologic modeling.

hydrologically-conditioned (hydro-conditioned) Processing of a Digital Elevation Model (DEM) or Triangulated Irregular Network (TIN) so that the flow of water is continuous across the entire terrain surface, including the removal of all spurious sinks or pits. The only sinks that are retained are the real ones on the landscape. Whereas hydrologically-enforced is relevant to drainage features that generally are mapped, hydrologically-conditioned is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether that flow is in a stream channel or not. The purpose for continuous flow is so that relations/links among basins/catchments can be known for large areas.

hydrologically-flattened (hydro-flattened) Processing of a lidar-derived surface (Digital Elevation Model (DEM) or Triangulated Irregular Network (TIN)) so that mapped water bodies, rivers, reservoirs, and other cartographically polygonal water surfaces are flat and, where appropriate, level from bank-to-bank. Additionally, surfaces of rivers and long reservoirs demonstrate a gradient change in elevation along their length, consistent with their natural behavior and the surrounding topography. In traditional photogrammetrically-compiled mapping, this process is accomplished automatically through the inclusion of measured breaklines in the digital terrain model (DTM). However, because lidar does not inherently include breaklines, a DEM or TIN derived solely from lidar points will depict water surfaces with unsightly and unnatural artifacts of triangulation. The process of hydro-flattening typically involves the addition of breaklines along the banks of specified water bodies, rivers, ponds, and streams. These breaklines establish elevations for the water surfaces that are consistent with the surrounding topography, and produce aesthetically acceptable water surfaces in the final derived DEM or TIN. Unlike hydro-conditioning and hydro-enforcement, hydro-flattening is not driven by any hydrologic and hydraulic (H&H) modeling requirements, but solely by cartographic mapping needs.

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 Digital Elevation Model (DEM), Triangulated Irregular Network (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 use 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.

I

intensity, lidar For discrete-return lidar instruments, intensity is the recorded amplitude of the reflected lidar pulse at the moment the reflection is captured as a return by the lidar instrument. Lidar intensity values can be affected by numerous factors such as the instantaneous setting of the instrument's Automatic Gain Control, angle of incidence, and so forth, and cannot be equated to a true measure of energy. In full-waveform systems, the entire reflection is sampled and recorded, and true energy measurements can be made for each return or overall reflection. Intensity values for discrete returns derived from a full-waveform system may or may not be calibrated to represent true energy.

Lidar intensity data make it possible to map variable textures in the form of a gray-scale image. Intensity return data enable automatic identification and extraction of objects such as buildings and impervious surfaces, and can aid in lidar point classification. In spite of their similar appearance, lidar intensity images differ from traditional panchromatic images in several important ways:

- Lidar intensity is a measure of the reflection of an active laser energy source, not natural solar energy.
- Lidar intensity images are aggregations of values at point samples. The value of a pixel does not represent the composite value for the area of that pixel.
- Lidar intensity images depict the surface reflectivity within an extremely narrow band of the infra-red spectrum, not the entire visible spectrum as in panchromatic images.
- Lidar intensity images are strongly affected by the angle of incidence of the laser to the target, and are subject to unnatural shadowing artifacts.
- The values on which lidar intensity images are based may or may not be calibrated to any standard reference. Intensity images usually contain wide variation of values within swaths, between swaths, and between lifts.

For these reasons, interpretation and analysis of lidar intensity images must be performed with unusually high care and skill.

J

K

Kalman filter A recursive minimum variance estimation technique that uses statistical models to weight each new measurement relative to past information and estimate quantities of interest having statistical characteristics. The technique can be considered a recursive least squares adjustment.

L

last return The last significant measurable portion of a return lidar pulse.

lattice A three-dimensional surface representation method created by a rectangular array of points spaced at a constant sampling interval in x and y directions relative to a common origin. A lattice differs from a grid in that it represents the value of the surface only at the lattice mesh points or elevation posts of the lattice, rather than the elevation of the cell area surrounding the centroid of a grid cell.

lever arm A relative position vector of one sensor with respect to another in a direct georeferencing system. For example, with aerial mapping cameras, there are lever arms between the inertial center of the Inertial Measurement Unit (IMU) and the phase center of the Global Positioning System (GPS) antenna, each with respect to the camera perspective center within the lens of the camera.

lidar An instrument that measures distance to a reflecting object by emitting timed pulses of light and measuring the time difference between the emission of a laser pulse and the reception of the pulse's reflection(s). The measured time interval for each reflection is converted to distance, which when combined with position and attitude information from Global Positioning System (GPS), Inertial Measurement Unit (IMU), and the instrument itself, allows the derivation of the 3-dimensional point location of the reflecting target's location.

lift A lift is a single take-off/landing cycle of a collection platform (fixed or rotary wing) within a lidar data collection project.

local accuracy *See* accuracy.

M

metadata Any information that is descriptive or supportive of a geospatial dataset. This would include formally structured and formatted metadata files (for example, eXtensible Markup Language (XML)-formatted Federal Geographic Data Committee (FGDC) metadata), reports (collection, processing, Quality Assurance/Quality Control (QA/QC)), and other supporting data (for example, survey points, shapefiles).

N

nadir The point or line directly beneath the collection platform , corrected for attitude variations. In lidar, this would correspond to the centerline of a collected swath.

nominal pulse spacing (NPS) A common measure of the density of a lidar dataset, it is the typical or average lateral distance between points in a lidar dataset, most often expressed in meters. It is often and most simply calculated as the square root of the average area per point. This value is predicted in mission planning and empirically calculated from the collected data. In high-density collections (<1 meter NPS), this may be directly expressed as Points Per Square Meter (ppsm). $PPSM = 1/NPS^2$.

O

OCONUS Outside of CONUS; not within the contiguous United States. *See* CONUS.

overage Those parts of a swath that are not necessary to form a complete single, non-overlapped, gap-free coverage with respect to the adjacent swaths. The non-tenderloin portions of a swath. *See* overlap, tenderloin.

overlap Any potion of a swath that also is covered by any portion of any other swath. *See* coverage, tenderloin.

P

percentile Although there is no accepted single definition of percentile, the following general definition can be used: A percentile is a measure that tells us what percent of the total frequency scored at or below that measure. A percentile rank is the percentage of scores that fall at or below a given score. The National Institute of Standards and Technology (NIST) recommends the following as the preferred method for calculating percentile:

$$n=(P / 100) * (N + 1).$$

NIST notes the following method, used by Microsoft Excel and other software packages, as an alternative:

$$n=((P / 100) * (N - 1) + 1)$$

As both methods yield similar results, particularly with large samples, either may be used.

point classification The assignment of a target identity classification to a particular lidar point or group of points.

point family The complete set of multiple returns reflected from a single lidar pulse.

point cloud A large set of three dimensional points, typically from a lidar collection. As a basic geographic information system (GIS) data type, a point cloud is differentiated from a typical point dataset in several key ways:

- Point clouds are almost always 3D,
- Point clouds have an order of magnitude more features than point datasets, and
- Individual point features in point clouds do not typically possess individually meaningful attributes; the informational value in a point cloud is derived from the relations among large numbers of features

preprocessing In lidar, the preprocessing of data most commonly refers to those steps employed in converting the collected Global Positioning System (GPS), Inertial Measurement Unit (IMU), instrument, and ranging information into an interpretable X-Y-Z point cloud. This includes generation of trajectory information, calibration of the dataset, and controlling the dataset to known ground references.

postprocessing In lidar, postprocessing refers to the processing steps applied to lidar data point clouds. This includes point classification, feature extraction (for example, building footprints, hydrographic features, and others), tiling, and generation of derivative products (Digital Elevation Models (DEMs), Digital Surface Model (DSMs), intensity images, and others).

Q

R

S

scan angle *See* field of view.

supplemental vertical accuracy (SVA) The result of a test of the accuracy of a lidar digital terrain model using 3-D Quality Assurance/Quality Control (QA/QC) checkpoints in a single land cover category. Computed using a nonparametric testing method (95th percentile), a supplemental vertical accuracy is always accompanied by a fundamental vertical accuracy. *See* percentile.

spatial distribution In lidar, the regularity or consistency of the point density within the collection. The theoretical ideal spatial distribution for a lidar collection is a perfect regular lattice of points with equal spacing on X and Y axes. Various factors prevent this ideal from being achieved, including the following:

- Instrument design (oscillating mirrors),
- Mission planning (difference between along-track and cross-track point spacing), and
- In-flight attitude variations (roll, pitch, and yaw).

swath The data resulting from a single flightline of collection. *See* flightline.

T

tenderloin The central portion of the swath that, when combined with adjacent swath tenderloins, forms a complete, single, non-overlapped, gap-free coverage. *See* overage, overlap.

triangulated irregular network (TIN) A vector data structure that partitions geographic space into contiguous, non-overlapping triangles. In lidar, the vertices of each triangle lidar points with x-, y-, and z-values. In most geographic applications, TINs are based on Delaunay triangulation algorithms in which no point in any given triangle lies within the circumcircle of any other triangle.

U

V

W

well-distributed For a dataset covering a rectangular area that has uniform positional accuracy, checkpoints should be distributed so that points are spaced at intervals of at least 10 percent of the diagonal distance across the dataset and at least 20 percent of the points are located in each quadrant of the dataset (adapted from the National Standards for Spatial Data Accuracy (NSSDA)). As related to this specification, these guidelines are applicable to each land cover class for which checkpoints are being collected.

withheld Within the LAS file specification, a single bit flag indicating that the associated lidar point is geometrically anomalous or unreliable and should be ignored for all normal processes. These points are retained because of their value in specialized analysis. Withheld points typically are identified and tagged during preprocessing or through the use of automatic classification routines. Examples of points typically tagged as withheld are listed below:

- Spatial outliers in either the horizontal or vertical domains.
- Geometrically unreliable points near the edge of a swath.

X

Y

Z

Appendixes

Appendix 1. Common Data Upgrades

- Independent 3rd-Party QA/QC by another Architecture & Engineering (AE) Contractor (encouraged)
- Lower NPS (greater point density)
- Increased Vertical Accuracy
- Full Waveform collection and delivery
- Additional Environmental Constraints
  - Tidal coordination, flood stages, crop/plant growth cycles, and the like
  - Shorelines corrected for tidal variations within a collection
- Top-of Canopy (First-Return) Raster Surface (tiled)
  - Raster representing the highest return within each cell is preferred
- Intensity Images (8-bit gray scale, tiled)
  - Interpolation based on 1st-Returns
  - Interpolation based on All-Returns, summed
- Detailed Classification (additional classes; table 1–1)
- Hydro-Enforced DEMs as an additional deliverable
- Hydro-Conditioned DEMs as an additional deliverable
- Breaklines (PolylineZ and PolygonZ) for single-line hydrographic features
  - Narrow streams not collected as double-line, culverts, and other similar features, including appropriate integration into delivered DEMs
- Breaklines (PolylineZ and PolygonZ) for other features (to be determined)
  - Including appropriate integration into delivered DEMs
- Extracted Buildings (PolygonZ)
  - Footprints with maximum elevation or height above ground as an attribute
- Other products as defined by requirements and agreed upon in advance of funding commitment

Table 1–1. Additional Point Cloud Classifications.

Code	Description
3	Low vegetation
4	Medium vegetation (use for single vegetation class)
5	High vegetation
6	Buildings, bridges, other man-made structures
n	Additional class(es) as agreed upon in advance

Appendix 2. Guidelines

Scan Angle

For oscillating mirror lidar systems, the total field of view should not exceed 40 degrees (within 20 degrees of nadir). U.S. Geological Survey (USGS) quality assurance on collections performed using scan angles wider than 34 degrees will be particularly rigorous in the edge-of-swath areas. Lidar systems that use rotating mirrors/prisms may be exempted from this guideline.

Swath Size

The processing report shall include detailed information on swath segmentation sufficient to allow reconstruction of the original swaths if needed.

Non-Tidal Boundary Waters

The elevation along the edge or edges should behave consistently throughout the project. May be a single elevation (for example, a lake) or gradient (for example, a river), as appropriate. If unusual changes in water surface elevation occur during the course of the collection, then the surface may be treated as a tidal boundary, as described in the next section. The reason for the changes must be documented in the project metadata.

Tidal Waters

Variations in water-surface elevation resulting in tidal variations during a collection should NOT be removed or adjusted, as this would require either the removal of valid, measured ground points or the introduction of unmeasured ground into the digital elevation model (DEM). The USGS National Geospatial Progam (NGP) priority is on the ground surface, and accepts occasional, unavoidable irregularities in tidal water surfaces.

Breaklines and Hydro-Flattening

The USGS does not require any particular process or methodology be used for hydro-flattening or for breakline collection, extraction, or integration. However, if breaklines are developed, the following general guidelines must be adhered to:

- Bare-earth lidar points that are in close proximity breaklines should be excluded from the DEM generation process. This is analogous to the removal of masspoints for the same reason in a traditional photogrammetrically compiled digital terrain model (DTM). The proximity threshold for reclassification as Ignored Ground is at the discretion of the data producer, but in general should not exceed the nominal pulse spacing (NPS). These points are to be retained in the delivered lidar point dataset and shall be reclassified as Ignored Ground (class value = 10) so that they may be subsequently identified.

- Delivered data must be sufficient for the USGS to effectively recreate the delivered DEMs using the lidar points and breaklines without substantial editing.

- The goal of hydro-flattening is to produce a topographic DEM that, with respect to water surfaces, resembles a DEM derived from traditional photogrammetric methods. Best professional judgment should be used to achieve this end.

Appendix 3. Hydro-Flattening Reference

The subject of modifications to lidar-based digital elevation models (DEM) is somewhat new and there is substantial variation in the understanding of the topic across the industry. The following material was developed to provide a definitive reference on the subject only as it relates to the creation of DEMs intended to be integrated into the U.S. Geological Survey (USGS) NED. The information presented here is not meant to supplant other reference materials and it should not be considered authoritative beyond its intended scope.

The term hydro-flattening also is new, coined for this document and to convey the USGS National Geospatial Program's (NGP) need for DEMs having a specific type of functional surface . It is not, at this time, a known or accepted term across the industry. It is our hope that its use and acceptance will expand beyond the USGS with the assistance of other industry leaders.

Hydro-flattening of DEMs is accomplished predominantly through the use of breaklines, and this method is considered standard. Although other techniques may exist to achieve similar results, this section assumes the use of breaklines. The USGS does not require the use of any specific technique.

The Digital Elevation Model Technologies and Applications: The DEM User's Manual, 2nd Edition (Maune, 2007) provides the following definitions related to the adjustment of DEM surfaces for hydrologic analyses.

- *Hydrologically Conditioned (Hydro-Conditioned)* Processing of a DEM or TIN so that the flow of water is continuous across the entire terrain surface, including the removal of all spurious sinks or pits. The only sinks that are retained are the real ones on the landscape. Whereas hydrologically-enforced is relevant to drainage features that are generally mapped, hydrologically-conditioned is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether that flow is in a stream channel or not. The purpose for continuous flow is so that relations/links among basins/catchments can be known for large areas. This term is specifically used when describing Elevation Derivatives for National Applications (EDNA), the dataset of NED derivatives made specifically for hydrologic modeling purposes.

- *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 use 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. See also the definition for hydrologically conditioned that has a slightly different meaning.

Whereas these are important and useful modifications, they result in surfaces that differ substantially from a traditional DEM. A hydro-conditioned surface has had its sinks filled and may have had its water-bodies flattened. This is necessary for correct flow modeling within and across large drainage basins. Hydro-enforcement extends this conditioning by requiring water bodies be leveled and streams flattened with the appropriate downhill gradient, and also by cutting through road crossings over streams (culvert locations) to allow a continuous flow path for water within the drainage. These treatments result in a surface on which water behaves as it physically does in the real world, and they are invaluable for specific types of hydraulic and hydrologic (H&H) modeling activities. Neither of these treatments is typical of a traditional DEM surface.

A traditional DEM such as the NED, on the other hand, attempts to represent the ground surface more the way a bird, or person in an airplane, sees it. On this surface, natural depressions exist, and roadways create apparent sinks because the roadway is depicted continuously without regard to the culvert beneath, making it an apparent dam. Bridges, it should be noted, are removed in most all types of DEMs because they are man-made, above-ground structures that have been added to the landscape.

Note: DEMs developed solely for orthophoto production may include bridges, as their presence can prevent the smearing of structures and reduce the amount of post-production correction of the final orthophoto. These are special use DEMs and are not relevant to this discussion.

For years, raster DEMs have been created from a digital terrain model (DTM) of masspoints and breaklines, which in turn were created through photogrammetric compilation from stereo imagery. Photogrammetric DTMs inherently contain breaklines defining the edges of water bodies, coastlines, single-line streams, and double-line streams and rivers, as well as numerous other surface features.

Lidar technology, however, does not inherently collect the breaklines necessary to produce traditional DEMs. Breaklines have to be developed separately through a variety of techniques, and either used with the lidar points in the generation of the DEM, or applied as a correction to DEMs generated without breaklines.

To maintain the consistent character of the NED as a traditional DEM, the USGS NGP requires that all DEMs delivered have their inland water bodies flattened. This does not imply that a complete network of topologically correct hydrologic breaklines be developed for every dataset; only those breaklines necessary to ensure that the conditions defined in the section called Hydro-flattening exist in the final DEM.

Appendix 4. Lidar Metadata Example


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    <citation>
      <citeinfo>
        <origin>We Map 4U, Inc.</origin>
          <pubdate>20101208</pubdate>
          <title>Lidar data for Phelps and Dent Counties, MO
            MO_Phelps-Dent-CO_2010
          </title>
        <geoform>Lidar point cloud</geoform>
      </citeinfo>
    </citation>
    <descript>
      <abstract>Geographic Extent: This dataset is lidar point cloud
        data, which encompasses a 1,000 meter buffer around Phelps and Dent Counties
        in Missouri, approximatly 829 square miles.
        Dataset Description: This dataset consists of 457 lidar point cloud .LAS
        swath files. Each .LAS file contains lidar point information, which has been
        calibrated, controlled, and classified. Each file represents a separate
        swath of lidar. Collected swath files that were larger than 2GB were
        initially written in multiple sub-swath files, each less than 2GB.
        Ground Conditions: water at normal levels; no unusual innundation; no snow;
        leaf off
      </abstract>
      <lidar>
        <ldrinfo>
          <ldrspec>USGS NGP Base Specification v1</ldrspec>
          <ldrsens>Optech Gemini Airborne Laser Terrain Mappers (ALTM)</ldrsens>
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    </laswheld>
    <lasolap> Swath “overage” points were identified in these files by adding
      16 to the standard classification values.
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  hydro-flattened Digital Elevation Model (DEM) with a 1.0 foot cell size.
  The data will be used by Federal Emergency Management Agency (FEMA) for
  floodplain mapping.
```

```
      These raw lidar point cloud data were used to create classified lidar LAS files,
      intensity images, 3D breaklines, hydro-flattened DEMs as necessary.
    </purpose>
    <supplinf>
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      CONTRACTOR: We Map4U, Inc.
      SUBCONTRACTOR:  Aerial Scanning Services, LLC
      Lidar data were acquired and calibrated by Aerial Scanning Services.
      All follow-on processing was completed by the prime contractor.
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  <useconst>None. However, users should be aware that temporal changes may have occurred
    since this dataset was collected and that some parts of these data may no longer
    represent actual surface conditions. Users should not use these data for critical
    applications without a full awareness of its limitations. Acknowledgement of the U.S.
    Geological Survey would be appreciated for products derived from these data.
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        <cntorg>We Map 4U, Data Acquisition Department</cntorg>
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  </native>
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        be computed for raw lidarpoint cloud swath files. The vertical accuracy
        was tested with 25 independent survey located in open terrain.  These
        check points were not used in the calibration or post processing of the
        lidar point cloud data.  The survey checkpoints were distributed
        throughout the project area.  Specifications for this project require
        that the FVA be 25 cm or better AccuracyZ at 95 percent confidence level.
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      <qvertpa>
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        <vertacce>The FVA was tested using 25 independent survey located in open terrain
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          The 25 independant check points were surveyed using  xxxx technique.  Elevations
          from the unclassified lidar surface were measured for the x,y location of each
          check point. Elevations interpolated from the lidar surface were then compared
          to the elevation values of the surveyed control.  The RMSE was computed to be
          0.097cm.
          AccuracyZ has been tested to meet 9.7 cm Fundamental Vertical Accuracy at 95
          Percent confidence level using RMSE(z) x 1.9600 as defined by the National
          Standards for Spatial Data Accuracy (NSSDA); assessed and reported using
          National Digital Elevation Program (NDEP)/ASPRS Guidelines.
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  <procdesc>Lidar Pre-Processing: Airborne GPS and IMU data were merged to develop
    a Single Best Estimate (SBET) of the lidar system trajectory for each lift.
    Lidar ranging data were initially calibrated using previous best parameters
    for this instrument and aircraft. Relative calibration was evaluated using
    advanced plane-matching analysis and parameter corrections derived. This
    was repeated iteratively until residual errors between overlapping swaths,
    across all project lifts, was reduced to 2cm or less. Data were then block
    adjusted to match surveyed calibration control. Raw data FVA were checked
    using independently surveyed checkpoints. Swath overage points were identified
    and tagged within each swath file. The results of the final calibration, FVA
    and horizontal accuracy assessments, and the “raw” swaths were forwarded
    to the client to obtain a Notice To Proceed on classification and derivative
    product generation.
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        <cntper>Manny Puntas</cntper>
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        </cntaddr>
```

```
          <cntvoice>555-555-556</cntvoice>
          <cntfax>555-5550-1236</cntfax>
          <cntemail>mpuntas@wemap4u.com</cntemail>
          <hours>Monday through Friday 8:00 AM to 4:00 PM (Central Time)</hours>
          <cntinst>If unable to reach the contact by telephone, please send an email.
            You should get a response within 24 hours.
          </cntinst>
        </cntinfo>
      </proccont>
    </procstep>
    <procstep>
      <procdesc>Lidar Post-Processing: The calibrated and controlled lidar
        swaths were processed using automatic point classification routines
        in proprietary software. These routines operate against the entire
        collection (all swaths, all lifts), eliminating character differences
        between files. Data were then distributed as virtual tiles to experienced
        lidar analysts for localized automatic classification, manual editing,
        and peer-based QC checks. Supervisory QC monitoring of work in progress
        and completed editing ensured consistency of classification character and
        adherence to project requirements across the entire project area.
        All classification tags are stored in the original swath files.
        After completion of classification and final QC approval, the FVA,
        SVAs, and CVA for the project are calculated. Sample areas for each
        Land cover type present in the project area was extracted and forwarded
        to the client, along with the results of the accuracy tests. Upon acceptance,
        the complete classified lidar swath files were delivered to the client.
      </procdesc>
      <srcused>Phelps-Dent_Co_NAIP_Imagery</srcused>
      <srcused>Phelps-Dent_Co_Lidar_Intensity_Imagery</srcused>
      <procdate>20100530</procdate>
      <proccont>
        <cntinfo>
        <cntorgp>
          <cntorg>We Map 4U, Data Acquisition Department</cntorg>
          <cntper>Manny Puntas</cntper>
        </cntorgp>
        <cntaddr>
          <addrtype>mailing and physical</addrtype>
          <address>123 Main St.</address>
          <city>Anytown</city>
          <state>MO</state>
          <postal>61234</postal>
          <country>USA</country>
        </cntaddr>
        <cntvoice>555-555-556</cntvoice>
        <cntfax>555-5550-1236</cntfax>
        <cntemail>mpuntas@wemap4u.com</cntemail>
        <hours>Monday through Friday 8:00 AM to 4:00 PM (Central Time)</hours>
        <cntinst>If unable to reach the contact by telephone, please send an email.
          You should get a response within 24 hours.
        </cntinst>
      </cntinfo>
    </proccont>
  </procstep>
 </lineage>
</dataqual>
<spdoinfo>
 <direct>Vector</direct>
 <ptvctinf>
  <sdtsterm>
    <sdtstype>Point</sdtstype>
    <ptvctcnt>764,567,423</ptvctcnt>
```

```
    </sdtsterm>
  </ptvctinf>
</spdoinfo>
<spref>
  <horizsys>
    <planar>
      <gridsys>
        <gridsysn>Universal Transverse Mercator</gridsysn>
          <utm>
            <utmzone>15</utmzone>
            <transmer>
              <sfctrmer>0.9996</sfctrmer>
              <longcm>-117.000000</longcm>
              <latprjo>0.0</latprjo>
              <feast>500000</feast>
              <fnorth>0.0</fnorth>
            </transmer>
          </utm>
        </gridsys>
        <planci>
          <plance>coordinate pair</plance>
          <coordrep>
            <absres>0.01</absres>
            <ordres>0.01</ordres>
          </coordrep>
          <plandu>meters</plandu>
        </planci>
    </planar>
    <geodetic>
      <horizdn>North American Datum of 1983</horizdn>
      <ellips>Geodetic Reference System 80</ellips>
      <semiaxis>6378137</semiaxis>
      <denflat>298.257222101</denflat>
    </geodetic>
  </horizsys>
  <vertdef>
    <altsys>
      <altdatum>North American Vertical Datum of 1988</altdatum>
      <altres> 0.01</altres>
      <altunits>meters</altunits>
      <altenc>Explicit elevation coordinate included with horizontal coordinates</altenc>
    </altsys>
  </vertdef>
</spref>
<distinfo>
  <distrib>
    <cntinfo>
      <cntperp>
        <cntper>Jim Brooks, GISP</cntper>
        <cntorg>Phelps-Dent Council of Government (PDCOG), GIS and Data Division</cntorg>
      </cntperp>
      <cntpos>Director</cntpos>
      <cntaddr>
        <addrtype>mailing and physical address</addrtype>
        <address>PDCOG, GIS Division</address>
        <address>123 ABD Street</address>
        <address> Suite 456</address>
        <city>Sometown</city>
        <state>MO</state>
        <postal>99999</postal>
        <country>USA</country>
      </cntaddr>
```

```
      <cntvoice>555-555-9999</cntvoice>
      <cntemail>jim.brooks@PDCOG.org</cntemail>
    </cntinfo>
  </distrib>
  <resdesc>The Phelps-Dent Council of Government (PDCOG)distributes data
    directly to program partners.
    Public access to the data is available from the USGS as listed below.
  </resdesc>
  <distliab>In no event shall the creators, custodians, or distributors of these
    data be liable for any damages arising out of its use, or from the inability
    of the customer to use these data for their intended application.
  </distliab>
 </distinfo>
 <metainfo>
  <metd> 20101206</metd>
  <metrd> 20101207</metrd>
  <metc>
    <cntinfo>
      <cntorgp>
        <cntorg>We Map 4U, Data Acquisition Department</cntorg>
        <cntper>John Smith</cntper>
      </cntorgp>
      <cntaddr>
        <addrtype>mailing and physical</addrtype>
        <address>123 Main St.</address>
        <city>Anytown</city>
        <state>MO</state>
        <postal>61234</postal>
        <country>USA</country>
      </cntaddr>
      <cntvoice>555-555-1234</cntvoice>
      <cnttdd>555-555-1122</cnttdd>
      <cntfax>555-5550-1235</cntfax>
      <cntemail>jsmith@wemap4u.com</cntemail>
      <hours>Monday through Friday 8:00 AM to 4:00 PM (Central Time)</hours>
      <cntinst> If unable to reach the contact by telephone, please send an email.
        You should get a response within 24 hours.
      </cntinst>
    </cntinfo>
  </metc>
  <metstdn>FGDC Content Standard for Digital Geospatial Metadata</metstdn>
  <metstdv>FGDC-STD-001-1998</metstdv>
  <metac>None</metac>
  <metuc>None</metuc>
  <metsi>
    <metscs>None</metscs>
    <metsc>Unclassified</metsc>
    <metshd>None</metshd>
  </metsi>
  <metextns>
    <onlink>None</onlink>
    <metprof>None</metprof>
  </metextns>
 </metainfo>
</metadata>
```

Appendix 5. Lidar Metadata Template


```
<?xml version=”1.0” encoding=”UTF-8”?>
<!--DOCTYPE metadata SYSTEM “fgdc-std-001-1998.dtd”-->
<metadata>
  <idinfo>
    <citation>
      <citeinfo>
        <origin> EXAMPLE: We Map 4U, Inc.
        <!--REQUIRED Element: Originator
          Name of the contractor that developed the dataset.
          Domain: “Unknown” free text
          -->
        </origin>
        <pubdate> 20101208
        <!--REQUIRED Element: Publication Date
          Date that the dataset was RELEASED. The field MUST be formatted YYYYMMDD
          Domain: “Unknown” “Unpublished Material” YYYYMMDD free text
          -->
        </pubdate>
        <title> EXAMPLE: Lidar data for Phelps and Dent Counties, MO
          MO_Phelps-Dent-CO_2010
          <!--REQUIRED Element: Title
            The name by which the dataset is known.
            If a Project ID in the following format has been issued for this project,
            include it in the title element [State_description_aquisition-date].
            Domain: free text
            -->
        </title>
        <geoform> EXAMPLE: Lidar point cloud
          <!--REQUIRED Element: Geospatial Data Presentation Form
            The mode in which the geospatial data are represented.
            Domain:  free text
            -->
        </geoform>
      </citeinfo>
    </citation>
    <descript>
      <abstract> EXAMPLE: Geographic Extent: This dataset is lidar point cloud
        data, which encompasses a 1,000 meter buffer around Phelps and Dent Counties
        in Missouri, approximatly 829 square miles.
        Dataset Description: This dataset consists of 457 lidar point cloud .LAS
        swath files. Each .LAS file contains lidar point information, which has been
        calibrated, controlled, and classified. Each file represents a separate
        swath of lidar. Collected swath files that were larger than 2GB were
        initially written in multiple sub-swath files, each less than 2GB.
        Ground Conditions: water at normal levels; no unusual innundation; no snow; leaf
        off
        <!--REQUIRED Element: Abstract
          A brief narrative summary of the dataset.
          It is desireable for the Abstract to include a consolidated summary other
          elements that are included elsewhere in this metadata file, for ease of use.
          Domain: free text
          -->
      </abstract>
      <lidar>
        <!-- REQUIRED Section: for Project, Swath, and Classified LAS metadata files -->
        <ldrinfo>
          <!--REQUIRED Group: This group of tags contains metadata about the sesnor and
            collection conditions.
            -->
```

```
<ldrspec>EXAMPLE: USGS-NGP Base Lidar Specification v1.0
  <!--REQUIRED Element: the lidar specification applicable to the point cloud
    -->
</ldrspec>
<ldrsens>EXAMPLE: Optech Gemini Airborne Laser Terrain Mappers (ALTM)
  <!--REQUIRED Element: the lidar sensor make and model -->
</ldrsens>
<ldrmaxnr>EXAMPLE: 4
  <!--REQUIRED Element: the maximum number of returns per pulse -->
</ldrmaxnr>
<ldrnps>EXAMPLE: 1.2
  <!--REQUIRED Element: the Nominal Pulse Spacing, in Meters -->
</ldrnps>
<ldrdens>EXAMPLE: 2
  <!--REQUIRED Element: the Nominal Pulse Spacing, in Points Per Square Meter
    -->
</ldrdens>
<ldrfltht>EXAMPLE: 3000
  <!--REQUIRED Element: the nominal flight height for the collection, in Meters
    -->
</ldrfltht>
<ldrfltsp>EXAMPLE: 115
  <!--REQUIRED Element: the nominal flight speed for the collection, in Knots
    -->
</ldrfltsp>
<ldrscana>EXAMPLE: 26
  <!--REQUIRED Element: the sensor scan angle, total, in Degrees -->
</ldrscana>
<ldrscanr>EXAMPLE: 40
  <!--REQUIRED Element: the scan frequency of the scanner, in Hertz -->
</ldrscanr>
<ldrpulsr>EXAMPLE: 120
    <!--REQUIRED Element: the pulse rate of the scanner, in Kilohertz -->
  </ldrpulsr>
<ldrpulsd>EXAMPLE: 10
  <!--REQUIRED Element: the pulse duration of the scanner, in Naonseconds -->
</ldrpulsd>
<ldrpulsw>EXAMPLE: 3
  <!--REQUIRED Element: the pulse width of the scanner, in Meters -->
</ldrpulsw>
<ldrwavel>EXAMPLE: 1064
  <!--REQUIRED Element: the central wavelength of the sensor laser, in
    Nanometers
    -->
</ldrwavel>
<ldrmpia>EXAMPLE: 0
  <!--REQUIRED Element: Whether the sensor was operated with Multiple Pulses In
    The Air, 0=No; 1=Y
    -->
</ldrmpia >
<ldrbmdiv>EXAMPLE: 0.3
  <!--REQUIRED Element: the beam divergence, in Milliradians -->
</ldrbmdiv>
<ldrswatw>EXAMPLE: 1200
  <!--REQUIRED Element: the nominal swath width on the ground, in Meters -->
</ldrswatw>
<ldrswato>EXAMPLE: 15
  <!--REQUIRED Element: the nominal swath overlap, as a Percentage -->
</ldrswato>
<ldrcrs> EXAMPLE: NAD_1983_UTM_Zone_15N_Meters
  <!--REQUIRED Element: This is the Horizontal Coordinate Reference System for
    the data.
```

```
      Details for the desired format are below.
      Go to the website: http://spatialreference.org/ref/
      Search for your CRS, then select the name that reflects your CRS,
      Select ESRI WKT
      Use the name that is within the first set of quotation marks.
      This name should consist of datum, coordinate system, and sometimes units
      all separated by underscores instead of spaces.
      When units are not already present, the units must be appended to the end
      of the string: "_Meters", "_Feet_US", "_Feet_Intl"
      -->
  </ldrcrs>
  <ldrgeoid>EXAMPLE: National Geodetic Survey (NGS) Geoid09
    <!--REQUIRED Element: Geoid used for vertical reference. -->
  </ldrgeoid>
</ldrinfo>
<ldraccur>
  <!-- REQUIRED Group: This group of tags contains information on point cloud
    accuracy. Not all tags within this group are mandatory.
    The FVA of the raw point cloud is required. CVA and SVA values for the
    classified point cloud are optional,but are required to be reported if they
    are available.
    ALL Values are reported in METERS.
    -->
  <ldrchacc>EXAMPLE: 0.5
    <!--REQUIRED Element: the calculated horizontal accuracy of the point cloud data
      -->
  </ldrchacc>
  <rawfva>EXAMPLE: 0.11
    <!--REQUIRED Element: the calculated fundamental vertical accuracy of the raw
      point cloud data
      -->
  </rawfva>
  <clsfva>EXAMPLE: 0.09
    <!--OPTIONAL Element: the calculated fundamental vertical accuracy of the
      classified point cloud data (required if available)
      -->
  </clsfva>
  <clscva>EXAMPLE: 0.188
    <!--OPTIONAL Element: the calculated consolidated vertical accuracy of the
      classified point cloud data (required if available)
      -->
  </clscva>
  <clssvas>
    <!--OPTIONAL Group for Raw swath points, REQUIRED Group for Classified LAS
      Tiles: Each land cover besides open ground will have a Supplemental
      Vertical Accuracy.
      The two tags under <clssvas> document the land cover type and the SVA value
      (Forest, in this case)
      This clssvas group will be repeated for each land cover class
      -->
    <svalctyp>EXAMPLE: Forest</svalctyp>
    <svavalue>EXAMPLE: 0.38</svavalue>
  </clssvas>
  <clssvas>
    <svalctyp>EXAMPLE: Agriculture</svalctyp>
    <svavalue>EXAMPLE: 0.21</svavalue>
  </clssvas>
  <clssvas>
    <svalctyp>EXAMPLE:Pasture/Meadow</svalctyp>
    <svavalue>EXAMPLE: 0.15</svavalue>
  </clssvas>
  <clssvas>
```

```
      <svalctyp>EXAMPLE: Scrub/Shrub</svalctyp>
      <svavalue>EXAMPLE: 0.11</svavalue>
    </clssvas>
    <clssvas>
      <svalctyp>EXAMPLE: Urban</svalctyp>
      <svavalue>EXAMPLE: 0.13</svavalue>
    </clssvas>
  </ldraccur>
  <lasinfo>
    <!-- REQUIRED Group: This group of tags contains information on the LAS version
      and classification values for the point cloud.
      -->
    <lasver>EXAMPLE: 1.3
    <!-- REQUIRED Element: The version of the LAS Standard applicable to this data
      set.
      -->
    </lasver>
    <lasprf>EXAMPLE: 6
      <!-- REQUIRED Element: The Point Data Record Format used for the point cloud.
        -->
    </lasprf>
    <laswheld>EXAMPLE: Withheld (ignore) points were identifed in these files using
      the standard LAS Withheld bit.
      <!-- REQUIRED Element: Describe how withheld points are identified.-->
    </laswheld>
    <lasolap>EXAMPLE: Swath “overage” points were identified in these files by
      adding 16 to the standard classification values.
      <!-- REQUIRED Element: This describes how overage points are identified.-->
    </lasolap>
    <lasintr>EXAMPLE: 11
      <!-- REQUIRED Element: This specifies the radiometric resolution of intensity
        values, in Bits.
        -->
    </lasintr>
    <lasclass>
      <!-- REQUIRED Section if LAS data are classified: Each lasclass section
        provides a code value and a description for that code.
        -->
      <clascode>EXAMPLE: 0</clascode>
      <clasitem>EXAMPLE: Never Processed</clasitem>
    </lasclass>
    <lasclass>
      <clascode>EXAMPLE: 1</clascode>
      <clasitem>EXAMPLE: Undetermined/Unclassified</clasitem>
    </lasclass>
    <lasclass>
      <clascode>EXAMPLE: 2</clascode>
      <clasitem>EXAMPLE: Bare-earth</clasitem>
    </lasclass>
    <lasclass>
      <clascode>EXAMPLE: 4</clascode>
      <clasitem>EXAMPLE: All vegetation</clasitem>
    </lasclass>
    <lasclass>
      <clascode>EXAMPLE: 6</clascode>
      <clasitem>EXAMPLE: All structures except bridges</clasitem>
    </lasclass>
    <lasclass>
      <clascode>EXAMPLE: 7</clascode>
      <clasitem>EXAMPLE: All noise</clasitem>
    </lasclass>
    <lasclass>
```

```
        <clascode>EXAMPLE: 8</clascode>
        <clasitem>EXAMPLE: Bare-earth Key Points</clasitem>
      </lasclass>
      <lasclass>
        <clascode>EXAMPLE: 9</clascode>
        <clasitem>EXAMPLE: Water</clasitem>
      </lasclass>
      <lasclass>
        <clascode>EXAMPLE: 10</clascode>
        <clasitem>EXAMPLE: Bridges</clasitem>
      </lasclass>
    </lasinfo>
  </lidar>
  <purpose>The purpose of these lidar data was to produce high accuracy 3D
    hydro-flattened Digital Elevation Model (DEM) with a 1.0 foot cell size.
    The data will be used by FEMA for flood-plain mapping.
    These raw lidar point cloud data were used to create classified lidar LAS files,
    intensity images, 3D breaklines, hydro-flattened DEMs as necessary.
    <!--REQUIRED Element: Purpose
      Why was the dataset was created? For what applications?
      What other products this dataset will be used to create: tiled classified LAS,
      DEM, and others, required deliverables, or interim products necessary to
      complete the project. What scales are appropriate or inappropriate for use?
      Domain: free text
      -->
  </purpose>
  <supplinf>
    USGS Contract No. G10PC01234
    CONTRACTOR: We Map4U, Inc.
    SUBCONTRACTOR: Aerial Scanning Services, LLC
    Lidar data were acquired and calibrated by Aerial Scanning Services.
    All follow-on processing was completed by the prime contractor.
    <!--OPTIONAL Element: Supplemental Information
      Enter other descriptive information about the dataset.
      Desirable information includes any deviations from project specifications and
      reasons. It also may include any other information that the contractor finds
      necessary or useful, such as contract number or summary of lidar technology.
      Remove this tag or clear the contents of this tag if none.
      Domain: free text
      -->
  </supplinf>
</descript>
<timeperd>
  <timeinfo>
    <!--REQUIRED Group: Time info: will be either:
      single date,
      OR multiple dates,
      OR a range of dates.
      Examples are provided for all three formats.
      Delete the ones that do not apply.
      -->
      <sngdate>
        <!--Begin the example of Single Date-->
        <caldate> 20100216
          <!--REQUIRED Element: Calendar Date
            This is the date of the LiDAR collection, if the collection
            was completed in one day. &#13
            The field MUST be formatted YYYYMMDD
            -->
        </caldate>
      </sngdate>
      <mdattim>
```

```
        <!-- Begin example of a multiple dates -->
        <sngdate>
          <caldate> 20100216
          <!--REQUIRED Element: Calendar Date
            This is the first date of the LiDAR collection, when
            multiple collection dates are specified.
            The field MUST be formatted YYYYMMDD
            -->
          </caldate>
        </sngdate>
        <sngdate>
          <caldate> 20100218
          <!--REQUIRED Element: Calendar Date
            This is the second date of the LiDAR collection, when
            multiple collection dates are specified.
            The field MUST be formatted YYYYMMDD
            REPEAT the sngdate and caldate tags for each collection date
            -->
        </caldate>
      </sngdate>
    </mdattim>
    <rngdates>
      <!-- Begin example of a date range -->
      <begdate> 20100216
        <!--REQUIRED Element: Beginning Date
          This is the beginning date of LiDAR collection.
          The field MUST be formatted YYYYMMDD
          -->
      </begdate>
      <enddate> 20100218
        <!--REQUIRED Element: Ending Date
          This is the ending date of LiDAR collection.
          The field MUST be formatted YYYYMMDD
          -->
      </enddate>
    </rngdates>
  </timeinfo>
  <current> EXAMPLE: ground condition
    <!--REQUIRED Element: Currrentness Reference
      Enter the basis on which the time period of content information is determined.
      Domain: “ground condition” “publication date” free text
      -->
  </current>
</timeperd>
<status>
  <progress> EXAMPLE: Partial: Lot 2 of 5
    <!--REQUIRED ELEMENT: Progress
      Enter the state of the dataset.
      Domain: “Complete” “Partial: Lot x of n”
      -->
  </progress>
  <update> EXAMPLE: None planned
    <!--REQUIRED ELEMENT: Maintenance and Update Frequency
      Enter the repeat cycle for the project.
      Domain: “Annually” “Unknown” “None planned” free text
      -->
  </update>
</status>
<spdom>
  <bounding>
    <westbc> -91.750000
      <!--REQUIRED Element: West Bounding Coordinate
```

```
      This value is the Western-most limit of coverage of the dataset
      expressed as longitude.
      This value will be negative in the United States.
      This value MUST be expressed in Decimal Degrees.
      Domain: -180.0<= West Bounding Coordinate< 180.0
      -->
  </westbc>
  <eastbc> -91.25000
    <!--REQUIRED Element: East Bounding Coordinate
      This value is the Eastern-most limit of coverage of the dataset
      expressed as longitude.
      This value will be negative in the United States.
      This value MUST be expressed in Decimal Degrees.
      Domain: -180.0<= East Bounding Coordinate<= 180.0
      -->
  </eastbc>
  <northbc> 38.00000
    <!--REQUIRED Element: North Bounding Coordinate
      This value is the Northern-most limit of coverage of the dataset
      expressed as latitude.
      This value will be positive in the United States.
      This value MUST be expressed in Decimal Degrees.
      Domain: -90.0<= North Bounding Coordinate<= 90.0
      -->
  </northbc>
  <southbc> 37.250000
    <!--REQUIRED Element: South Bounding Coordinate
      This value is the Southern-most limit of coverage of the dataset
      expressed as latitude.
      This value will be positive in the United States.
      This value MUST be expressed in Decimal Degrees.
      Domain: -90.0<= South Bounding Coordinate<= 90.0
      -->
  </southbc>
 </bounding>
 <lboundng>
  <leftbc> 584800
    <!--REQUIRED Element: This value is the Western-most coordinate of limit of
      coverage of the dataset expressed in the Coordinate Reference System in
      which the data are delivered.
      -->
  </leftbc>
  <rightbc> 664800
    <!--REQUIRED Element: This value is the Eastern-most coordinate of limit of
      coverage of the dataset expressed in the Coordinate Reference System in
      which the data are delivered.
      -->
  </rightbc>
  <topbc> 4225400
    <!--REQUIRED Element: This value is the Northern-most coordinate of limit of
      coverage of the dataset expressed in the Coordinate Reference System in
      which the data are delivered.
      -->
  </topbc>
  <bottombc> 4141400
    <!--REQUIRED Element: This value is the Southern-most coordinate of limit of
      coverage of the dataset expressed in the Coordinate Reference System in
      which the data are delivered.
      -->
  </bottombc>
 </lboundng>
</spdom>
```

```
<keywords>
  <theme>
    <themekt> EXAMPLE: None
      <!--REQUIRED Element: Theme Keyword Thesaurus
        A formally registered thesaurus or a similar authoritative source of theme
        keywords.
        Domain: “None” free text
        -->
    </themekt>
    <themekey> EXAMPLE: Elevation data
      <!--REQUIRED Element: Theme Keyword: Elevation data (required)-->
    </themekey>
    <themekey> EXAMPLE: Lidar
      <!--REQUIRED Element: Theme Keyword: Lidar (required)-->
    </themekey>
    <themekey> EXAMPLE: Hydrology
      <!--Enter any additional applicable theme keywords, use only ONE keyword for each
        themekey tag. Repeat the themekey tag as many times as necessary.
        Domain: free text
        -->
    </themekey>
  </theme>
  <place>
    <placekt> EXAMPLE: None
      <!--REQUIRED Element: Place Keyword Thesaurus
        Reference to a formally registered thesaurus or a similar authoritative
        source of place keywords.
        Domain: “None” “Geographic Names Information System” free text
        -->
    </placekt>
    <placekey> EXAMPLE: Missouri
      <!--REQUIRED Element: Place Keyword
        For multi-state projects, make a separate entry for each state.
        List only one state for each placekey tag.
        -->
    </placekey>
    <placekey> EXAMPLE: Phelps County
      <!--REQUIRED Element: Place Keyword
        For multi-county projects, make a separate entry for each county.
        List only one county for each placekey tag.
        -->
    </placekey>
    <placekey> EXAMPLE: Dent County
    </placekey>
    <placekey> EXAMPLE: Mark Twain National Forest
      <!--Enter any additional applicable place keywords, for example cities or
        landmarks.
        Use only one keyword for each placekey tag.
        Repeat the placekey tag as many times as necessary.
        Domain: free text
        -->
    </placekey>
  </place>
</keywords>
<accconst> EXAMPLE: No restrictions apply to these data.
  <!--REQUIRED Element: Access Constraints.
    Enter restrictions and legal prerequisites for
    accessing the dataset. These include any access constraints applied
    to assure the protection of privacy or intellectual property, and
    any special restrictions or limitations on obtaining the dataset.
    Domain: “None” free text
    -->
```

```
</accconst>
<useconst> EXAMPLE: None. However, users should be aware that temporal changes may
  have occurred since this dataset was collected and that some parts of these data may
  no Longer represent actual surface conditions.  Users should not use these data for
  critical applications without a full awareness of it’s limitations. Acknowledgement
  of the U.S. Geological Survey would be appreciated for products derived from these
  data.
  <!--REQUIRED Element: Enter restrictions and legal prerequisites for
    using the dataset after access is granted. These include any use
    constraints applied to assure the protection of privacy or intellectual
    property, and any special restrictions or limitations on using the dataset.
    Domain: “None” free text
    -->
</useconst>
<ptcontac>
  <cntinfo>
    <cntorgp>
      <cntorg> EXAMPLE: We Map 4U, Data Acquisition Department
        <!--REQUIRED Element: Contact Organization:
          Name of the organization that created the data and is knowledgeable about
          the data.
          Domain: free text
          -->
      </cntorg>
      <cntper> EXAMPLE: Jane Smith
        <!--REQUIRED Element: Contact Person
          The name of the individual who is knowledgeable about the data.
          Domain: free text
          -->
      </cntper>
    </cntorgp>
    <cntaddr>
      <addrtype> EXAMPLE: mailing and physical
        <!--REQUIRED Element: Address Type
          The type of address that follows.
          Only required for “mailing” or “mailing and physical”. If the contractor
          has a different mailing and physical address, the physical address
          does not need to be included. This section may be repeated if you would
          like to provide a separate physical address.
          Domain: “mailing” “physical” “mailing and physical”, free text
          -->
      </addrtype>
      <address> EXAMPLE: 123 Main St.
        <!--REQUIRED Element: Address
          The address of the contractor.
          For multiple line addresses the address tag may be repeated as many times
          as needed.
          Domain: free text
          -->
      </address>
      <city> EXAMPLE: Anytown
        <!--REQUIRED Element: City
          The city of the address.
          Domain: free text
          -->
      </city>
      <state> EXAMPLE: MO
        <!--REQUIRED Element: State
          The state or province of the address.
          Domain: free text
          -->
      </state>
```

```
      <postal> EXAMPLE: 61234
        <!--REQUIRED Element: Postal Code
          Enter the ZIP or other postal code of the address.
          Domain: free text
          -->
      </postal>
      <country> EXAMPLE: USA
        <!--OPTIONAL Element: Country
          The country of the address.
          Domain: free text
          -->
      </country>
    </cntaddr>
    <cntvoice> EXAMPLE: 555-555-1234
      <!--REQUIRED Element: Contact Voice Telephone
        The telephone number by which individuals can speak to the
        organization or individual responsible for the data.
        Domain: free text
        -->
    </cntvoice>
    <cnttdd> EXAMPLE: 555-555-1122
      <!--OPTIONAL Element: Contact TDD/TTY Telephone
        The telephone number by which hearing-impaired individuals
        can contact the organization or individual.
        Domain: free text
        -->
    </cnttdd>
    <cntfax> EXAMPLE: 555-5550-1235
      <!--OPTIONAL Element: Contact Fax
        The telephone number of a facsimile machine of the organization
        or individual.
        Domain: free text
        -->
    </cntfax>
    <cntemail> EXAMPLE: jsmith@wemap4u.com
      <!--OPTIONAL Element: Contact E-mail Address
        The email address of the organization or individual.
        Domain: free text
        -->
    </cntemail>
    <hours> EXAMPLE: Monday through Friday 8:00 AM to 4:00 PM (Central Time)
      <!--OPTIONAL Element: Hours of Service
        The time period when individuals can speak to the organization or individual.
        Domain: free text
        -->
    </hours>
    <cntinst> EXAMPLE: If unable to reach the contact by telephone,
      please send an email. You should get a response within 24 hours.
      <!--OPTIONAL Element: Contact Instructions
        Supplemental instructions on how or when to contact the individual or
        organization.
        Domain: free text
        -->
    </cntinst>
  </cntinfo>
</ptcontac>
<native> EXAMPLE: Optech DASHMap 4.2200; ALS Post Processor 2.70 Build#15;
  GeoCue Version 6.1.21.4; Windows XP Operating System
  \\server\directory path\*.LAS
  17 GB
  <!--REQUIRED: Native Data Set Environment
    Description of the dataset in the producer's processing
```

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      environment, including items such as the name of the software (including version),
      the computer operating system, file name (including host-, path-, and filenames),
      and the dataset size.
      Domain: free text
      -->
  </native>
</idinfo>
<dataqual>
  <logic> EXAMPLE: Data cover the entire area specified for this project.
    <!--REQUIRED Element: Logical Consistency Report
      Describe the fidelity of relations in the data
      structure of the lidar data: tests of valid values
      or topological tests. Identify software used and
      the date of the tests.
      Domain: free text
      -->
  </logic>
  <complete> EXAMPLE: These raw LAS data files include all data points collected.
    No points have been removed or excluded.
    A visual qualitative assessment was performed to ensure data completeness.
    There are no void areas or missing data.  The raw point cloud is of good
    quality and data passes Fundamental Vertical Accuracy specifications.
    <!--REQUIRED Element: Completeness Report
      Document the inclusion or omissions of features for
      the dataset.  Minimum width or area thresholds.
      Selection criteria or other rules used to derive the
      dataset.
      Domain: free text
      -->
  </complete>
  <posacc>
    <vertacc>
      <vertaccr> EXAMPLE: The specifications require that only Fundamental Vertical
        Accuracy (FVA) be computed for raw lidarpoint cloud swath files.
        The vertical accuracy was tested with 25 independent survey located in open
        terrain. These check points were not used in the calibration or post
        processing of the lidar point cloud data. The survey checkpoints were
        distributed throughout the project area. Specifications for this project
        require that the FVA be 25 cm or better AccuracyZ at 95 percent confidence
        level.
        <!--REQUIRED Element: Vertical Positional Accuracy Report
          An explanation of the accuracy of the vertical coordinate measurements
          and a description of the tests used.
          Domain: free text
          -->
      </vertaccr>
      <qvertpa>
        <vertaccv> EXAMPLE: 0.19 meters AccuracyZ at 95 percent Confidence Interval
          <!--REQUIRED Element: Vertical Positional Accuracy Value
            Vertical accuracy expressed in (ground) meters.
            Clearly state whether this value is RMSEz or AccuracyZ
            Domain: free text
            -->
        </vertaccv>
        <vertacce> The FVA was tested using 25 independent survey located in open
          terrain terrain. The survey checkpoints were distributed throughout the
          project area. The 25 independant check points were surveyed using xxxx
          technique. Elevations from the unclassified lidar surface were measured
          for the x,y location of each check point.
          Elevations interpolated from the lidar surface were then compared to the
          elevation values of the surveyed control.   The RMSE was computed to be
          0.097m. AccuracyZ has been tested to meet 9.7 cm Fundamental Vertical
```

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        Accuracy at 95 Percent confidence level using RMSE(z) x 1.9600 as defined
        by the National Standards for Spatial Data Accuracy (NSSDA); assessed and
        reported using National Digital Elevation Program (NDEP)/ASRPS Guidelines.
        <!--REQUIRED Element: Vertical Positional Accuracy Explanation
          Identification of the test that yielded the Vertical Positional Accuracy
          Value.
          Domain: free text
          -->
      </vertacce>
    </qvertpa>
  </vertacc>
</posacc>
<lineage>
  <srcinfo>
    <!-- The srcinfo section of the metadata MUST be repeated for each data source
      that contributed making this unclassified LAS swath dataset. This includes,
      but is not limited to, 1) ground control used for calibrating the lidar data,
      2) the actual lidar aquistion data, and 3) independent ground control used to
      assess the accuracy of the lidar point cloud.
      -->
    <srccite>
      <citeinfo>
        <origin> EXAMPLE: Jiffy Survey, Inc
          <!--REQUIRED Element: Originator
            This the name of an organization or individual that
            developed the dataset. If the creation of this data source was created
            by a subcontractor, the subcontractors name and contact information
            should be entered as the source for that contributing data set.
            Domain: "Unknown" free text
            -->
        </origin>
        <pubdate> 20100115
          <!--REQUIRED element: Date of Publication
            Enter the date when the dataset is published or otherwise made available
            for release.
            The format of this date must be YYYMMDD.
            Domain: "Unknown" "Unpublished material" free date
            -->
        </pubdate>
        <title> EXAMPLE: Ground Control for Phelps and Dent County, MO lidar project
          <!--REQUIRED Element: Title
            The name by which the first contributing dataset is known.
            Domain: free text
            -->
        </title>
        <geoform> EXAMPLE: vector digital data and tabular data
          <!--OPTIONAL Element: Enter the mode in which the geospatial data are
            represented.
            Domain: (the listed domain is partially from pp. 88-91 in Anglo-American
            Committee on Cataloguing of Cartographic Materials, 1982, Cartographic
            materials: A manual of interpretation for AACR2: Chicago,
            American Library Association):
            "atlas" "audio" "diagram" "document" "globe" "map" "model" "multimedia
            presentation" "profile" "raster digital data" "remote-sensing image"
            "section" "spreadsheet" "tabular digital data" "vector digital data"
            "video" "view" free text
            -->
        </geoform>
        <pubinfo>
          <pubplace> EXAMPLE: Jiffy Survey, Inc.
            <!--REQUIRED Element: Publication Place
              The name of the city (and state or province, and country, if needed to
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          identify the city) the originator of the dataset.
          Domain: free text
          -->
      </pubplace>
      <publish> EXAMPLE: Jiffy Survey, Inc., GPS department
        <!--Enter the name of the individual or organization that published the
          dataset.
          Domain: free text
          -->
      </publish>
    </pubinfo>
    <othercit> EXAMPLE: None.
      <!--OPTIONAL Element: Other Citation Details
        Other information required to complete the citation.
        Domain: free text
        -->
    </othercit>
    <onlink> EXAMPLE:  ftp://JiffySurveyftp.com/data/outgoing/Task1/
      <!--OPTIONAL Element: Online Linkage
        IF APPLICABLE: The URL of an online computer resource that contains the
        dataset.
        Domain: free text
        -->
    </onlink>
  </citeinfo>
</srccite>
<srcscale> Example: 50
  <!--OPTIONAL Element: Source Scale Denominator
    IF APPLICABLE: The denominator of the representative fraction on a map
    (for example, on a 1:24,000-scale map, the Source Scale Denominator is 24000).
    Domain: Source Scale Denominator > 1
    -->
</srcscale>
<typesrc> EXAMPLE: CD-ROM
  <!--REQUIRED Element: Type of Source Media
    The medium of the first source dataset.
    Domain: “paper” “stable-base material” “microfiche” “microfilm”
    “audiocassette” “chart” “filmstrip” “transparency” “videocassette”
    “videodisc” “videotape” “physical model” “computer program” “disc”
    “cartridge tape” “magnetic tape” “online” “CD-ROM”
    “electronic bulletin board” “electronic mail system” free text
    -->
</typesrc>
<srctime>
  <timeinfo>
    <sngdate>
      <caldate> 201001003
        <!--REQUIRED Element: Calendar Date
          This is the date of the first source dataset was created.
          The field MUST be formatted YYYYMMDD
          -->
      </caldate>
    </sngdate>
  </timeinfo>
  <srccurr> EXAMPLE: ground condition
    <!--REQUIRED Elemenet: Source Currentness Reference
      The basis on which the source time period of content information of the
      source dataset is determined.
      Domain: “ground condition” “publication date” free text
      -->
  </srccurr>
</srctime>
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    <srccitea> EXAMPLE: Phelps_Co_lidar_gnd_ctrl
      <!--REQUIRED Element: Source Citation Abbreviation
        Enter short-form alias for the source citation.
        Each source MUST HAVE A UNIQUE ID.
        This ID will be used to reference these source data in the Process Step
        sections below.
        Domain: free text
        -->
    </srccitea>
    <srccontr> EXAMPLE: This data source was used (along with the airborne GPS/IMU
     Data) to georeferencing of the lidar point cloud data.
      <!--REQUIRED Element: Source Contribution
        Brief statement identifying the information contributed.
        Domain: free text
        -->
    </srccontr>
  </srcinfo>
   <srcinfo>
    <srccite>
      <citeinfo>
        <origin>USDA</origin>
        <pubdate> 20090606</pubdate>
        <title>NAIP Imagery for Phelps and Dent County, MO lidar project</title>
        <geoform>raster orthoimagery</geoform>
        <pubinfo>
          <pubplace>USGS-EROS</pubplace>
          <publish>USGS-EROS</publish>
        </pubinfo>
        <othercit>None</othercit>
        <onlink></onlink>
      </citeinfo>
    </srccite>
    <srcscale>50</srcscale>
    <typesrc>online</typesrc>
    <srctime>
      <timeinfo>
        <sngdate>
          <caldate>20090101</caldate>
        </sngdate>
      </timeinfo>
      <srccurr>ground condition</srccurr>
    </srctime>
    <srccitea>Phelps-Dent_Co_NAIP_Imagery</srccitea>
    <srccontr>This data source was used (along with the lidar intensity imagery)
      to classify the lidar point cloud data.
    </srccontr>
  </srcinfo>
  <srcinfo>
    <srccite>
      <citeinfo>
        <origin>We Map 4U, Inc.</origin>
        <pubdate>20101208</pubdate>
        <title>Lidar Intensity Imagery for Phelps and Dent County, MO</title>
        <geoform>raster orthoimagery</geoform>
        <pubinfo>
          <pubplace>USGS-EROS</pubplace>
          <publish>USGS-EROS</publish>
        </pubinfo>
        <othercit>None</othercit>
        <onlink></onlink>
      </citeinfo>
    </srccite>
```

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  <srcscale>50</srcscale>
  <typesrc>online</typesrc>
  <srctime>
    <timeinfo>
  <rngdates>
    <begdate>20100216</begdate>
    <enddate>20100218</enddate>
  </rngdates>
    </timeinfo>
    <srccurr>ground condition</srccurr>
  </srctime>
  <srccitea>Phelps-Dent_Co_Lidar_Intensity_Imagery</srccitea>
  <srccontr>This data source was used (along with NAIP imagery)
    to classify the lidar point cloud data.
  </srccontr>
</srcinfo>
<procstep>
  <procdesc> EXAMPLE: Lidar Pre-Processing: Airborne GPS and IMU data were merged
    to develop a Single Best Estimate (SBET) of the lidar system trajectory for
    each lift. Lidar ranging data were initially calibrated using previous best
    parameters for this instrument and aircraft. Relative calibration was evaluated
    using advanced plane-matching analysis and parameter corrections derived. This
    was repeated iteratively until residual errors between overlapping swaths,
    across all project lifts, was reduced to 2cm or less. Data were then block
    adjusted to match surveyed calibration control. Raw data FVA were checked
    using independently surveyed checkpoints. Swath overage points were identified
    and tagged within each swath file. The results of the final calibration, FVA
    and horizontal accuracy assessments, and the "raw" swaths were forwarded
    to the client to obtain a Notice To Proceed on classification     and derivative
    product generation.
    <!--Enter an explanation of the event and related parameters or tolerances.
      Domain: free text
      -->
  </procdesc>
  <srcused> EXAMPLE: Phelps_Co_lidar_gnd_ctrl
    <!--Enter the Source Citation Abbreviation of a dataset used in the processing
      step.
      Domain: Source Citation Abbreviations from the Source Information entries for
      the dataset.
      -->
  </srcused>
  <procdate> 20100131
    <!--Enter the date when the event was completed.
      Domain: "Unknown" "Not complete" free date
      -->
  </procdate>
  <srcprod> EXAMPLE: LiDAR datasets with USGS classifications
    <!--Enter the Source Citation Abbreviation of an intermediate dataset that
      (1) is significant in the opinion of the data producer, (2) is generated in
      the processing step, and (3) is used in later processing steps.
      Domain: Source Citation Abbreviations from the Source Information entries
      for the dataset.
      -->
  </srcprod>
  <proccont>
    <cntinfo>
      <cntorgp>
        <cntorg> EXAMPLE: We Map 4U, Data Acquisition Department
          <!--Enter the name of the organization to which the contact type applies.
            Domain: free text
            -->
        </cntorg>
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        <cntper> EXAMPLE: Manny Puntas
          <!--Enter the name of the individual to which the contact type applies.
            Domain: free text
            -->
        </cntper>
      </cntorgp>
      <cntaddr>
        <addrtype>mailing and physical</addrtype>
        <address>123 Main St.</address>
        <city>Anytown</city>
        <state>MO</state>
        <postal>61234</postal>
        <country>USA</country>
      </cntaddr>
      <cntvoice>555-555-556</cntvoice>
      <cntfax>555-5550-1236</cntfax>
      <cntemail>mpuntas@wemap4u.com</cntemail>
      <hours>Monday through Friday 8:00 AM to 4:00 PM (Central Time)</hours>
      <cntinst> If unable to reach the contact by telephone, please send an email.
        You should get a response within 24 hours.
      </cntinst>
    </cntinfo>
  </proccont>
</procstep>
<procstep>
  <procdesc>Lidar Post-Processing: The calibrated and controlled lidar
    swaths were processed using automatic point classification routines
    in proprietary software. These routines operate against the entire
    collection (all swaths, all lifts), eliminating character differences
    between files. Data were then distributed as virtual tiles to experienced
    lidar analysts for localized automatic classification, manual editing,
    and peer-based QC checks. Supervisory QC monitoring of work in progress
    and completed editing ensured consistency of classification character and
    adherence to project requirements across the entire project area.
    All classification tags are stored in the original swath files.
    After completion of classification and final QC approval, the FVA,
    SVAs, and CVA for the project are calculated. Sample areas for each
    land cover  type present in the project area were extracted and forwarded
    to the client, along with the results of the accuracy tests. Upon acceptance,
    the complete classified lidar swath files were delivered to the client.
  </procdesc>
  <srcused>Phelps-Dent_Co_NAIP_Imagery</srcused>
  <srcused>Phelps-Dent_Co_Lidar_Intensity_Imagery</srcused>
  <procdate>20100530</procdate>
  <proccont>
    <cntinfo>
      <cntorgp>
        <cntorg>We Map 4U, Data Acquisition Department</cntorg>
        <cntper>Manny Puntas</cntper>
        </cntorgp>
      <cntaddr>
        <addrtype>mailing and physical</addrtype>
        <address>123 Main St.</address>
        <city>Anytown</city>
        <state>MO</state>
        <postal>61234</postal>
        <country>USA</country>
      </cntaddr>
      <cntvoice>555-555-556</cntvoice>
      <cntfax>555-5550-1236</cntfax>
      <cntemail>mpuntas@wemap4u.com</cntemail>
      <hours>Monday through Friday 8:00 AM to 4:00 PM (Central Time)</hours>
```

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        <cntinst> If unable to reach the contact by telephone, please send an email.
          You should get a response within 24 hours.
        </cntinst>
      </cntinfo>
    </proccont>
  </procstep>
 </lineage>
</dataqual>
<spdoinfo>
 <direct> EXAMPLE: Vector
  <!--REQUIRED Element: Enter the system of objects used to represent space in the
    dataset.
    Domain: “Point” “Vector” “Raster”
    -->
 </direct>
 <ptvctinf>
  <sdtsterm>
    <sdtstype> EXAMPLE: Point
      <!--REQUIRED Element: SDTS Point and Vector Object Type
        Enter  name of point and vector spatial objects used to l
        ocate zero-, one-, and two-dimensional spatial locations
        in the dataset.
        Domain: (The domain is from “Spatial Data Concepts,” which is Chapter 2 of
        Part 1 in Department of Commerce, 1992, Spatial Data Transfer Standard
        (SDTS) (Federal Information Processing Standard 173): Washington,
        Department of Commerce, National Institute of Standards and Technology):
        “Point” “Entity point” “Label point” “Area point” “Node, planar graph”
        “Node, network” “String” “Link” “Complete chain” “Area chain”
        “Network chain, planar graph” “Network chain, nonplanar graph”
        “Circular arc, three point center” “Elliptical arc” “Uniform B-spline”
        “Piecewise Bezier” “Ring with mixed composition”
        “Ring composed of strings” “Ring composed of chains”
        “Ring composed of arcs” “G-polygon” “GT-polygon composed of rings”
        “GT-polygon composed of chains”
        “Universe polygon composed of rings”
        “Universe polygon composed of chains”
        “Void polygon composed of rings” “Void polygon composed of chains”
        -->
    </sdtstype>
    <ptvctcnt> EXAMPLE: 764,567,423
      <!--OPTIONAL Element: Point and Vector Count
        Enter the total number of the point or vector object type occurring in the
        dataset.
        Domain: Point and Vector Object Count > 0
        -->
    </ptvctcnt>
  </sdtsterm>
 </ptvctinf>
</spdoinfo>
<spref>
 <horizsys>
  <planar>
    <gridsys>
        <!--REQUIRED Section: The section should be filled out with the relevant
        parameters for the coordinate reference system for the data. Usually it will
        be UTM or a State Plane Zone. Delete the irrelevant section below.
        -->
      <gridsysn> EXAMPLE: Universal Transverse Mercator
        <!--Enter name of the grid coordinate system.
          Domain: “Universal Transverse Mercator” “Universal Polar Stereographic”
          “State Plane Coordinate System 1927” “State Plane Coordinate System 1983”
          “ARC Coordinate System” “other grid system”
```

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      -->
    </gridsysn>
    <utm>
      <utmzone> EXAMPLE: 15
        <!--Enter the identifier for the UTM zone.
          Type: integer
          Domain:
          1 <= UTM Zone Number <= 60 for the northern hemisphere;
          -60 <= UTM Zone Number <= -1 for the southern hemisphere
          -->
      </utmzone>
      <transmer>
        <sfctrmer>0.9996
          <!--Enter a multiplier for reducing a distance obtained from a map by
            computation or scaling to the actual distance along the Central Meridian.
            Domain: Scale Factor at Central Meridian > 0.0
            -->
        </sfctrmer>
        <longcm>-117.000000
          <!--Enter the line of longitude at the center of a map projection
            generally used as the basis for constructing the projection.
            Type: real
            Domain: -180.0 <= Longitude of Central Meridian < 180.0
            -->
        </longcm>
        <latprjo>0.0
          <!--Enter latitude chosen as the origin of rectangular coordinates for
            a map  projection.
            Domain: -90.0 <= Latitude of Projection Origin <= 90.0
            -->
        </latprjo>
        <feast>500000
          <!--Enter the value added to all “x” values in the rectangular
            coordinates for a map projection. This value frequently is assigned
            to eliminate negative numbers.
            Expressed in the unit of measure identified in Planar Coordinate Units.
            Domain: free real
            -->
        </feast>
        <fnorth>0.0
          <!--Enter the value added to all “y” values in the rectangular
            coordinates for a map projection. This value frequently is assigned
            to eliminate negative numbers.
            Expressed in the unit of measure identified in Planar Coordinate Units.
            Domain: free real
            -->
        </fnorth>
      </transmer>
    </utm>
    <spcs>
      <spcszone>
        <!--Enter identifier for the SPCS zone.
          Domain: Four-digit numeric codes for the State Plane Coordinate Systems
          based on the North American Datum of 1927 are found in Department of
          Commerce, 1986, Representation of geographic point locations for
          information interchange (Federal Information Processing Standard 70-1):
          Washington: Department of Commerce, National Institute of Standards and
          Technology. Codes for the State Plane Coordinate Systems based on the
          North American Datum of 1983 are found in Department of Commerce, 1989
          (January), State Plane Coordinate System of 1983 (National Oceanic and
          Atmospheric Administration Manual NOS NGS 5): Silver Spring, Maryland,
          National Oceanic and Atmospheric Administration, National Ocean Service,
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    Coast and Geodetic Survey.
    -->
</spcszone>
<!-------------------------------------------------------------------------------->
<lambertc>
  <stdparll>
    <!--Enter line of constant latitude at which the surface of the Earth
      and the plane or developable surface intersect.
      Domain: -90.0 <= Standard Parallel <= 90.0
      -->
  </stdparll>
  <longcm>
    <!--Enter the line of longitude at the center of a map projection
      generally used as the basis for constructing the projection.
      Domain: -180.0 <= Longitude of Central Meridian < 180.0
      -->
  </longcm>
  <latprjo>
    <!--Enter latitude chosen as the origin of rectangular coordinates for
      a map projection.
      Domain: -90.0 <= Latitude of Projection Origin <= 90.0
      -->
  </latprjo>
  <feast>
    <!--Enter the value added to all “x” values in the rectangular
      coordinates for a map projection. This value frequently is assigned
      to eliminate negative numbers.
      Expressed in the unit of measure identified in Planar Coordinate Units.
      Domain: free real
      -->
  </feast>
  <fnorth>
    <!--Enter the value added to all “y” values in the rectangular
      coordinates for a map projection. This value frequently is assigned
      to eliminate negative numbers.
      Expressed in the unit of measure identified in Planar Coordinate Units.
      Domain: free real
      -->
  </fnorth>
</lambertc>
<!-------------------------------------------------------------------------------->
<transmer>
  <sfctrmer>
    <!--Enter a multiplier for reducing a distance obtained from a map by
      computation or scaling to the actual distance along the central
      meridian.
      Domain: Scale Factor at Central Meridian > 0.0
      -->
  </sfctrmer>
  <longcm>
    <!--Enter the line of longitude at the center of a map projection
      generally used as the basis for constructing the projection.
      Type: real
      Domain: -180.0 <= Longitude of Central Meridian < 180.0
      -->
  </longcm>
  <latprjo>
    <!--Enter latitude chosen as the origin of rectangular coordinates for
      a map  projection.
      Domain: -90.0 <= Latitude of Projection Origin <= 90.0
      -->
  </latprjo>
```

```
  <feast>
    <!--Enter the value added to all “x” values in the rectangular
      coordinates for a map projection. This value frequently is assigned
      to eliminate negative numbers.
      Expressed in the unit of measure identified in Planar Coordinate Units.
      Domain: free real
      -->
  </feast>
  <fnorth>
    <!--Enter the value added to all “y” values in the rectangular
      coordinates for a map projection. This value frequently is assigned
      to eliminate negative numbers.
      Expressed in the unit of measure identified in Planar Coordinate Units.
      Domain: free real
      -->
  </fnorth>
</transmer>
<!------------------------------------------------------------------------------------>
<obqmerc>
  <sfctrlin>
    <!--Enter a multiplier for reducing a distance obtained from a map by
      computation or scaling to the actual distance along the center line.
      Domain: Scale Factor at Center Line > 0.0
      -->
  </sfctrlin>
  <obqlazim>
    <azimangl>
      <!--Enter angle measured clockwise from north, and expressed in degrees.
        Domain: 0.0 <= Azimuthal Angle < 360.0
        -->
    </azimangl>
    <azimptl>
      <!--Enter longitude of the map projection origin.
        Domain: -180.0 <= Azimuth Measure Point Longitude < 180.0
        -->
    </azimptl>
  </obqlazim>
  <obqlpt>
    <obqllat>
      <!--Enter latitude of a point defining the oblique line.
        Domain: -90.0 <= Oblique Line Latitude <= 90.0
        -->
    </obqllat>
    <obqllong>
      <!--Enter longitude of a point defining the oblique line.
        Domain: -180.0 <= Oblique Line Longitude < 180.0
        -->
    </obqllong>
  </obqlpt>
  <latprjo>
    <!--Enter latitude chosen as the origin of rectangular coordinates for
      a map projection.
      Domain: -90.0 <= Latitude of Projection Origin <= 90.0
      -->
  </latprjo>
  <feast>
    <!--Enter the value added to all “x” values in the rectangular
      coordinates for a map projection. This value frequently is assigned
      to eliminate negative numbers.
      Expressed in the unit of measure identified in Planar Coordinate Units.
        Domain: free real
        -->
```

```
            </feast>
            <fnorth>
              <!--Enter the value added to all "y" values in the rectangular
                coordinates for a map projection. This value frequently is assigned
                to eliminate negative numbers.
                Expressed in the unit of measure identified in Planar Coordinate Units.
                Domain: free real
                -->
            </fnorth>
          </obqmerc>
          <!------------------------------------------------------------------------------>
          <polycon>
            <longcm>
              <!--Enter the line of longitude at the center of a map projection
                generally used as the basis for constructing the projection.
                Domain: -180.0 <= Longitude of Central Meridian < 180.0
                -->
            </longcm>
            <latprjo>
              <!--Enter latitude chosen as the origin of rectangular coordinates
                for a map projection.
                Domain: -90.0 <= Latitude of Projection Origin <= 90.0
                -->
            </latprjo>
            <feast>
              <!--Enter the value added to all "x" values in the rectangular
                coordinates for a map projection. This value frequently is assigned
                to eliminate negative numbers.
                Expressed in the unit of measure identified in Planar Coordinate Units.
                Domain: free real
                -->
            </feast>
            <fnorth>
              <!--Enter the value added to all "y" values in the rectangular
                coordinates for a map projection. This value frequently is assigned
                to eliminate negative numbers.
                Expressed in the unit of measure identified in Planar Coordinate Units.
                Domain: free real
                -->
            </fnorth>
          </polycon>
          <!------------------------------------------------------------------------------>
        </spcs>
      </gridsys>
      <planci>
        <plance>coordinate pair</plance>
        <coordrep>
          <absres>0.01</absres>
          <ordres>0.01</ordres>
        </coordrep>
        <plandu>meters</plandu>
      </planci>
    </planar>
    <geodetic>
      <horizdn>EXAMPLE: North American Datum of 1983
        <!--REQUIRED Element: Enter the identification given to the reference system
          used for defining the coordinates of points.
          Domain: "North American Datum of 1927" "North American Datum of 1983"
          free text
          -->
      </horizdn>
      <ellips>EXAMPLE: Geodetic Reference System 80
```

```
        <!--REQUIRED Element: Enter identification given to established representations
          of the Earth’s shape.
          Domain: “Clarke 1866” “Geodetic Reference System 80” free text
          -->
      </ellips>
      <semiaxis>6378137
        <!--REQUIRED Element: Enter radius of the equatorial axis of the ellipsoid.
          Domain: Semi-major Axis > 0.0
          -->
      </semiaxis>
      <denflat>298.257222101
        <!--REQUIRED Element: Enter the denominator of the ratio of the difference
          between the equatorial and polar radii of the ellipsoid when the numerator
          is set to 1.
          Domain: Denominator of Flattening > 0.0
          -->
      </denflat>
    </geodetic>
  </horizsys>
  <vertdef>
    <altsys>
      <altdatum> EXAMPLE: North American Vertical Datum of 1988
        <!--REQUIRED Element: Vertical Datum: The surface of reference from which
          vertical distances are measured.
          Domain: “National Geodetic Vertical Datum of 1929”
          “North American Vertical Datum of 1988”
          free text
          -->
      </altdatum>
      <altres> 0.01
        <!-- REQUIRED Element: Vertical Resolution: The minimum distance possible
          between two adjacent elevation (altitude) values, expressed in Altitude
          Distance Units of measure.
          Domain: Altitude Resolution > 0.0
          -->
      </altres>
      <altunits>  EXAMPLE: meters
        <!--REQUIRED Element: Units in which altitudes are recorded.
          Domain: “meters” “feet” free text
          -->
      </altunits>
      <altenc> EXAMPLE: Explicit elevation coordinate included with horizontal
        coordinates
        <!--REQUIRED Element: Altitude Encoding Method: The means used to encode the
          elevations.
          Domain: “Explicit elevation coordinate included with horizontal coordinates”
          “Implicit coordinate” “Attribute values”
          -->
      </altenc>
    </altsys>
  </vertdef>
</spref>
<eainfo>
  <!--SECTION: Entity and Attribute Information
    THIS SECTION IS NOT REQUIRED FOR LIDAR LAS DELIVERABLES.
    It is only required for deliverable data classified as a Feature Class.
    -->
</eainfo>
<distinfo>
  <!--SECTION: Distribution Information: Information about the distributor of and
    options for obtaining the dataset.
    THIS SECTION SHOULD ONLY BE POPULATED IF SOME ORGANIZATION OTHER THAN USGS HAS
```

```
      DISTRIBUTION RIGHTS TO THE DATA.
      -->
    <distrib>
      <cntinfo>
        <cntorgp>
          <cntorg> Leave blank unless an organization outside of USGS has distribution
            rights to the data.
          </cntorg>
          <cntper> Leave blank unless an organization outside of USGS has distribution
            rights to the data.
          </cntper>
        </cntorgp>
        <cntaddr>
          <addrtype> Leave blank unless an organization outside of USGS has distribution
            rights to the data.
          </addrtype>
          <address> Leave blank unless an organization outside of USGS has distribution
            rights to the data.
          </address>
          <city> Leave blank unless an organization outside of USGS has distribution
            rights to the data.
          </city>
          <state> Leave blank unless an organization outside of USGS has distribution
            rights to the data.
          </state>
          <postal> Leave blank unless an organization outside of USGS has distribution
            rights to the data.
          </postal>
          <country> Leave blank unless an organization outside of USGS has distribution
            rights to the data.
          </country>
        </cntaddr>
        <cntvoice> Leave blank unless an organization outside of USGS has distribution
          rights to the data.
        </cntvoice>
        <cntemail> Leave blank unless an organization outside of USGS has distribution
          rights to the data.
        </cntemail>
      </cntinfo>
    </distrib>
    <resdesc> Leave blank unless an organization outside of USGS has distribution
      rights to the data.
    </resdesc>
    <distliab> Leave blank unless an organization outside of USGS has distribution
      rights to the data.
    </distliab>
  </distinfo>
  <metainfo>
    <!-- REQUIRED SECTION: Metadata Reference Information: Information on the
      currentness of the metadata information, and the party responsible for the
      metadata.
      -->
    <metd> 20101206
      <!--REQUIRED Element: Metadata Date: The date that the metadata were created or
        last updated.
        Must be in the format YYYYMMDD.
        -->
    </metd>
    <metrd> 20101207
      <!--OPTIONAL Element: Metadata Review Date: The date of the latest review of the
        metadata entry.
        Must be in the format YYYYMMDD.
```

```
      Domain: Metadata Review Date later than Metadata Date
      -->
    </metrd>
    <metc>
      <cntinfo>
        <cntorgp>
          <cntorg> EXAMPLE: We Map 4U, Data Acquisition Department
            <!--REQUIRED Element: Contact Organization: The name of the organization
              which is responsible for creating the metadata.
              Domain: free text
              -->
          </cntorg>
          <cntper> EXAMPLE: John Smith
            <!--REQUIRED Element: Contact Person: The name of the individual who is the
              contact person concerning the metadata.
              Domain: free text
              -->
          </cntper>
        </cntorgp>
        <cntaddr>
          <addrtype> EXAMPLE: mailing and physical
            <!--REQUIRED Element: Address Type: The type of address that follows.
              Only required for “mailing” or “mailing and physical”. If the contractor
              has a different mailing and physical address, the physical address does
              not need to be included.
              Domain: “mailing” “physical” “mailing and physical”, free text
              -->
          </addrtype>
          <address> EXAMPLE: 123 Main St.
            <!--REQUIRED Element: Address: The address of the contractor responsible
              for the metadata. For multiple line addresses the address tag may be
              repeated as many times as needed.
              Domain: free text
              -->
          </address>
          <city> EXAMPLE: Anytown
            <!--REQUIRED Element: City: The city of the address.
              Domain: free text
              -->
          </city>
          <state> EXAMPLE: MO
            <!--REQUIRED Element: State: The state or province of the address.
              Domain: free text
              -->
          </state>
          <postal> EXAMPLE: 61234
            <!--REQUIRED Element: Postal Code: Enter the ZIP or other postal code
              of the address.
              Domain: free text
              -->
          </postal>
          <country> EXAMPLE: USA
            <!--OPTIONAL Element: Country: The country of the address.
              Domain: free text
              -->
          </country>
        </cntaddr>
        <cntvoice> EXAMPLE: 555-555-1234
          <!--REQUIRED Element: Contact Voice Telephone: The telephone number by which
            individuals can speak to the organization or individual responsible for the
            metadata.
            Domain: free text
```

```
      -->
    </cntvoice>
    <cnttdd> EXAMPLE: 555-555-1122
      <!--OPTIONAL Element: Contact TDD/TTY Telephone: The telephone number by which
        hearing-impaired individuals can contact the organization or individual.
        Domain: free text
        -->
    </cnttdd>
    <cntfax> EXAMPLE: 555-5550-1235
      <!--OPTIONAL Element: Contact Fax: The telephone number of a facsimile machine
        of the organization or individual.
        Domain: free text
        -->
    </cntfax>
    <cntemail> EXAMPLE: jsmith@wemap4u.com
      <!--OPTIONAL Element: Contact E-mail Address: The email address of the
        organization or individual.
        Domain: free text
        -->
    </cntemail>
    <hours> EXAMPLE: Monday through Friday 8:00 AM to 4:00 PM (Central Time)
      <!--OPTIONAL Element: Hours of Service: The time period when individuals can
        speak to the organization or individual.
        Domain: free text
        -->
    </hours>
    <cntinst> EXAMPLE: If unable to reach the contact by telephone, please send an
      email. You should get a response within 24 hours.
      <!--OPTIONAL Element: Contact Instructions: Supplemental instructions on how
        or when to contact the individual or organization.
        Domain: free text
        -->
    </cntinst>
  </cntinfo>
</metc>
<metstdn> EXAMPLE: FGDC Content Standard for Digital Geospatial Metadata
  <!--REQUIRED Element: Metadata Standard: Enter the name of the metadata
    standard used to document the dataset.
    Domain: "FGDC Content Standard for Digital Geospatial Metadata" free text
    -->
</metstdn>
<metstdv> EXAMPLE: FGDC-STD-001-1998
  <!--REQUIRED Element: Metadata Standard Veriosn: Enter identification of the
    version of the metadata standard used to document the dataset.
    Domain: free text
    -->
</metstdv>
<metac> EXAMPLE: None.
  <!--OPTIONAL Element: Metadata Access Constraints: Restrictions and legal
    prerequisites for accessing the metadata. These include any access constraints
    applied to assure the protection of privacy or intellectual property, and any
    special restrictions or limitations on obtaining the metadata.
    Domain: free text
    -->
</metac>
<metuc> EXAMPLE: None.
  <!--OPTIONAL Element: Metadata Use Constraints: Restrictions and legal prerequisites
    for using the metadata after access is granted. These include any metadata use
    constraints applied to assure the protection of privacy or intellectual property,
    and any special restrictions or limitations on using the metadata.
    Domain: free text
    -->
```

```
    </metuc>
    <metsi>
      <metscs> EXAMPLE: None.
        <!--REQUIRED IF APPLICABLE: Metadata Security Classification System: Name of
          the classification system for the metadata.
          Domain: free text
          -->
      </metscs>
      <metsc> EXAMPLE: Unclassified
        <!--REQUIRED IF APPLICABLE: Metadata Security Classification: Name of the
          handling restrictions on the metadata.
          Domain: “Top secret” “Secret” “Confidential” “Restricted” “Unclassified”
          “Sensitive” free text
          -->
      </metsc>
      <metshd> EXAMPLE: NONE
        <!--REQUIRED IF APPLICABLE: Metadata Security Handling Description: Additional
          information about the restrictions on handling the metadata.
          Domain: free text
          -->
      </metshd>
    </metsi>
    <metextns>
      <!-- Metadata Extensions Group: REQUIRED IF APPLICABLE. A reference to extended
        elements to the standard which may be defined by a metadata producer or a user
        community. Extended elements are elements outside the Standard, but needed by
        the metadata producer. If extended elements are created, they must follow the
        guidelines in Appendix D, Guidelines for Creating Extended Elements to the
        Content Standard for Digital Geospatial Metadata.
        -->
      <!--This section may be repeated as necessary-->
      <onlink> EXAMPLE: None
        <!--REQUIRED IF APPLICABLE: Online Linkage: URL for the resource that contains
          the metadata extension information for thedataset.
          -->
      </onlink>
      <metprof> EXAMPLE: None
        <!--REQUIRED IF APPLICABLE: Profile Name: Name of a document that describes the
          application of the Standard to a specific user community.
          -->
      </metprof>
    </metextns>
  </metainfo>
</metadata>
```

Supplemental Information

USGS National Elevation Dataset (NED) Web site:
http://www.ned.usgs.gov

USGS Center for Lidar Information Coordination and Knowledge (CLICK) Web site:
http://www.lidar.cr.usgs.gov

MP-Metadata Parser:
http://geology.usgs.gov/tools/metadata

National Institute of Standards and Technology (NIST) Percentile Information:
http://itl.nist.gov/div898/handbook/prc/section2/prc252.htm

Publishing support provided by:
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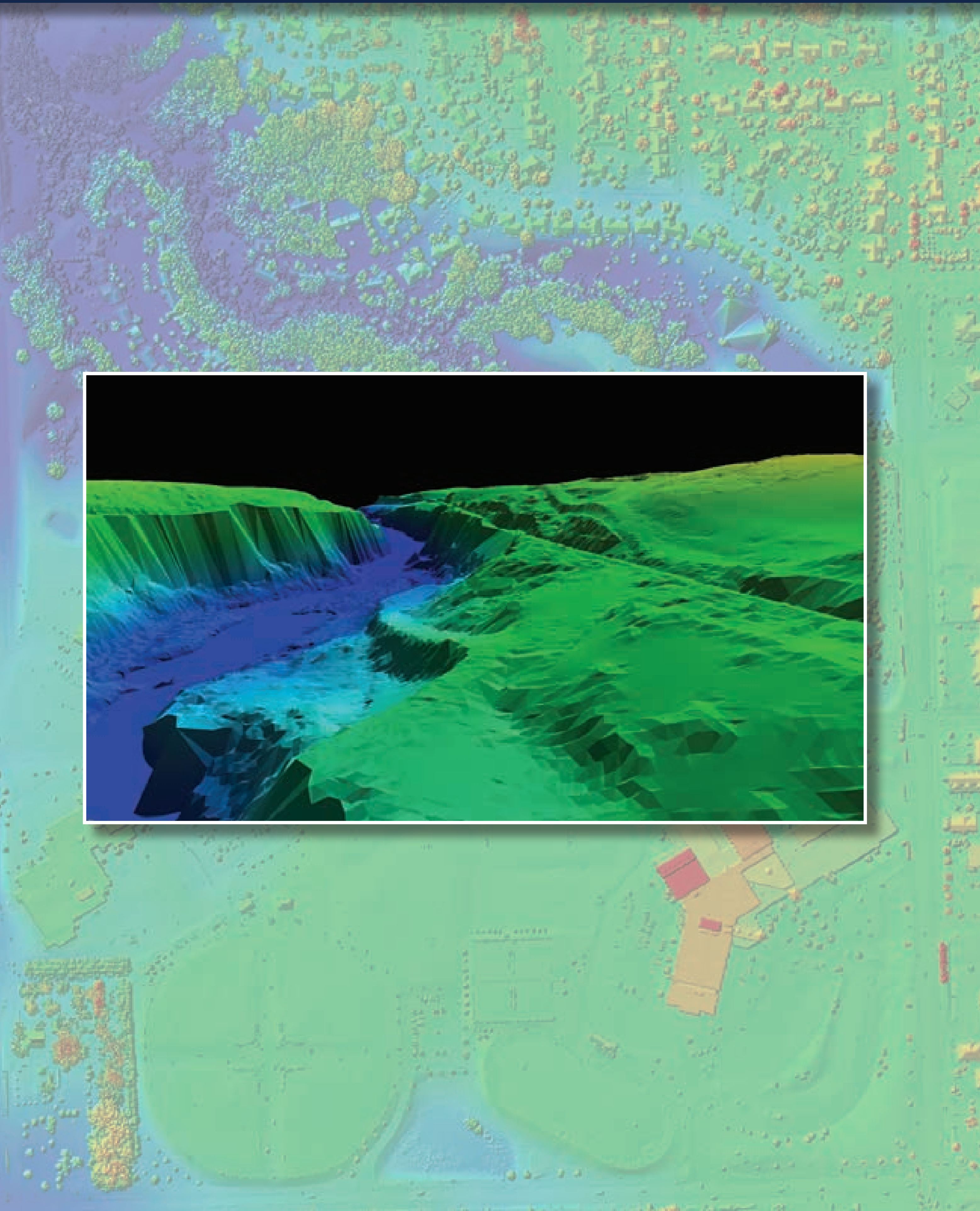
http://eros.usgs.gov/



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