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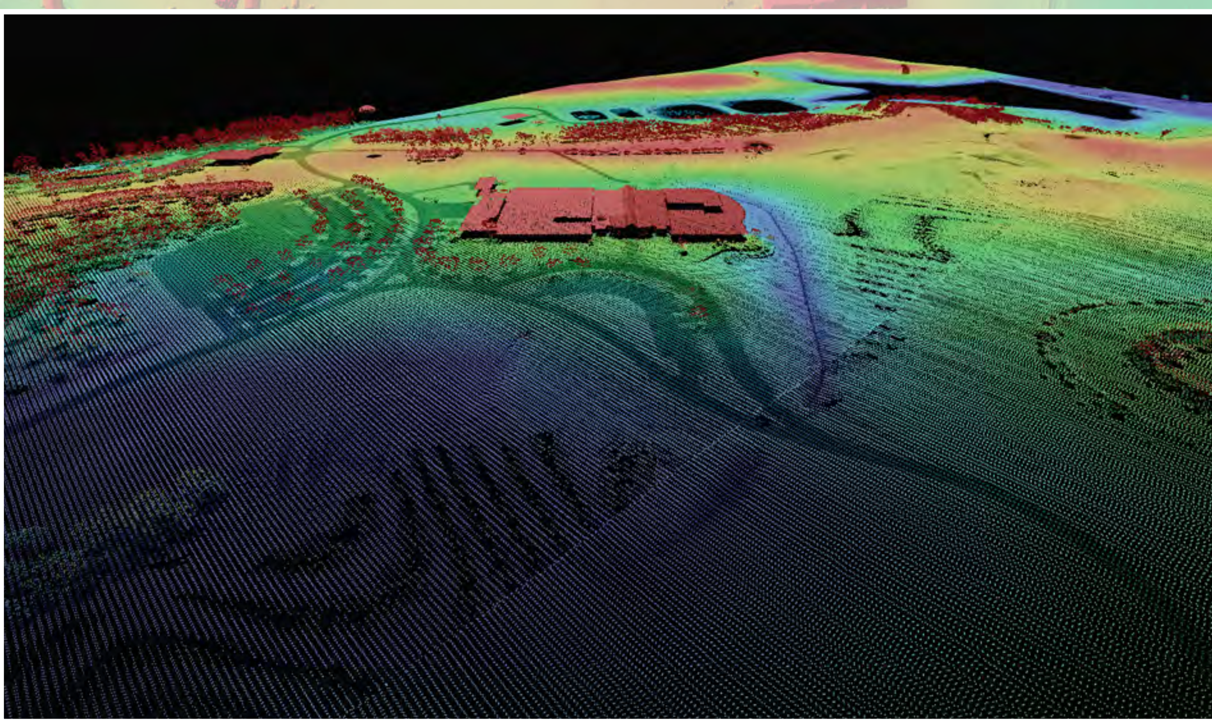
National Geospatial Program

Lidar Base Specification

Chapter 4 of
Section B, U.S. Geological Survey Standards
Book 11, Collection and Delineation of Spatial Data



Techniques and Methods 11–B4
Version 1.0, August 2012
Version 1.1, October 2014
Version 1.2, November 2014
Version 1.3, February 2018

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

Cover. Background: Image depicts a hillshade first-return light detection and ranging (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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RYAN K. ZINKE, Secretary

U.S. Geological Survey
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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
	Area	
hectare	2.4710538	acre
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)

Datum

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

Height, as used in this specification, refers to distance above the ground elevation.

Abbreviations

2D	2-dimensional (feature vertices are defined in *x* and *y* with no elevation information)
2.5D	2.5-dimensional (feature vertices are defined in *x* and *y* with a single elevation attribute for the entire feature)
3D	3-dimensional (feature vertices are defined in *x*, *y*, and *z*)
3DEP	3D Elevation Program
ACC_r	accuracy in the radial direction that includes both *x* and *y*
ACC_z	accuracy in the *z* direction
ANPD	aggregate nominal pulse density
ANPS	aggregate nominal pulse spacing
ARRA	American Recovery and Reinvestment Act
ASPRS	American Society for Photogrammetry and Remote Sensing
BPA	buffered project area
cm	centimeter
CONUS	conterminous United States
CR	carriage return
CRS	coordinate reference system
CSDGM	Content Standard for Digital Geospatial Metadata
CVA	consolidated vertical accuracy
DEM	digital elevation model
DPA	defined project area
DSM	digital surface model
DTM	digital terrain model
EDNA	Elevation Derivatives for National Applications
EPSG	European Petroleum Survey Group
EVLR	extended variable length record
FGDC	Federal Geographic Data Committee
FID	feature identifier
ft	foot
FVA	fundamental vertical accuracy
GB	gigabyte
GIS	geographic information system
GPS	global positioning system
H&H	hydrologic and hydraulic
ha	hectare

ID	identifier
IMU	inertial measurement unit
in.	inch
IOGP	International Association of Oil and Gas Producers
ISO	International Standards Organization
km	kilometer
km^2	square kilometer
LAS	LAS file format and extension
LBS	Lidar Base Specification (this document)
LF	line feed
lidar	light detection and ranging
m	meter
m^2	square meter
mi	mile
mi^2	square mile
MP	Metadata Parser
n/a	not available or not applicable
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NDEP	National Digital Elevation Program
NED	National Elevation Dataset
NEEA	National Enhanced Elevation Assessment
NGP	National Geospatial Program
NGS	National Geodetic Survey
NHD	National Hydrography Dataset
NL	new line
NPD	nominal pulse density
NPS	nominal pulse spacing
NSSDA	National Standards for Spatial Data Accuracy
NVA	nonvegetated vertical accuracy
OGC	Open Geospatial Consortium
pls/m^2	pulses per square meter
QA/QC	quality assurance/quality control
QL	quality level
RMSD	root mean square difference
$RMSD_z$	root mean square difference in the *z* direction

RMSE	root mean square error
$RMSE_r$	root mean square error in the radial direction that includes both *x* and *y* errors.
$RMSE_x$	root mean square error in the *x* direction
$RMSE_y$	root mean square error in the *y* direction
$RMSE_z$	root mean square error in the *z* direction
SVA	supplemental vertical accuracy
TIN	triangulated irregular network
URL	Uniform Resource Locator
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VLR	variable length record
VVA	vegetated vertical accuracy
WKT	well-known text
XML	eXtensible Markup Language

Lidar Base Specification

By Hans Karl Heidemann

Abstract

In late 2009, a $14.3 million allocation from the American Recovery and Reinvestment Act (ARRA) for new light detection and ranging (lidar) elevation data acquisition prompted the U.S. Geological Survey (USGS) National Geospatial Program (NGP) to develop a common minimum specification for all lidar data acquired for The National Map. Released as a working draft in 2010 and formally published in 2012, the USGS–NGP Lidar Base Specification (LBS) was quickly embraced by numerous States, counties, and foreign countries as the foundation for their own lidar specifications.

Prompted by a growing appreciation for the wide applicability and inherent value of lidar, a consortium of Federal agencies commissioned the National Enhanced Elevation Assessment (NEEA) study in 2010 to quantify the costs and benefits of a national lidar program. Published in 2012, the NEEA report documented a substantial return on such an investment, defined five quality levels (QL) for elevation data, and recommended an 8-year collection cycle of QL2 lidar data as the optimum balance of benefit and affordability. In response to the study, the USGS–NGP established the 3D Elevation Program (3DEP) in 2013 as the interagency vehicle through which the NEEA recommendations could be realized.

Lidar is a quickly evolving technology and much has changed in the industry since the previous version of the Lidar Base Specification (LBS) was published. Lidar data have improved in accuracy and spatial resolution, the American Society for Photogrammetry and Remote Sensing has revised the geospatial accuracy standards, industry standard file formats have been expanded, additional applications for lidar have become accepted, and the need for interoperable data across collections has been realized. This revision to the LBS addresses some of those changes and provides continued guidance towards a nationally consistent lidar dataset.

Introduction

As the designated Office of Management and Budget Circular A–16 (Office of Management and Budget, 2002) lead agency for topographic elevation data, the U.S. Geological Survey (USGS), through the National Geospatial Program (NGP), has developed and adopted the Lidar Base Specification (LBS) as the base specification for the national interagency 3D Elevation Program (3DEP). This specification, developed with input from a broad coalition of Federal, State, and industry light detection and ranging (lidar) interests, also may serve, in whole or in part, as the foundation for many other lidar specifications. Overall movement throughout the industry toward more consistent practices in the collection, handling, processing, documentation, and delivery of lidar data will allow the technology and data to become more useful to a broader user base and thereby benefit the Nation as a whole.

Although research and commercial mapping applications have used lidar data for more than two decades, lidar is still considered a relatively new technology. Advancements and improvements in instrumentation, software, processes, applications, and understanding are constantly being refined or developed. It would not be possible to develop a single set of guidelines and specifications that addresses and keeps pace with all of these advances. The experience and research of the NGP pertaining to the lidar technology currently (2017) being used in the industry forms the basis for this specification. Furthermore, the NGP acknowledges that the lidar industry in general has not developed or adopted a common set of best practices for numerous processes and technical assessments (for example, measurement of density and distribution, classification accuracy, and calibration quality). The USGS encourages the development of such best practices with industry partners, other government agencies, and the appropriate professional organizations.

It is important to understand that this specification exists to define the needs of 3DEP, of which two primary goals are (1) to build a national lidar dataset that supports the variety of applications identified in the National Enhanced Elevation Assessment (NEEA) study (Dewberry, 2012); and (2) to realize the benefits and cost efficiencies associated with a coordinated national program. Unlike most other lidar data procurement specifications, which largely focus on the products derived from lidar data such as the bare-earth digital elevation model (DEM), this specification places particular emphasis on the handling of the source lidar data. This specification is intended to ensure that the complete source dataset remains intact and viable to support the wide variety of DEM and non-DEM science and mapping applications that can benefit from lidar technology. The source dataset includes the data, metadata, descriptive documentation, quality information, and ancillary data—collected in accordance with the minimum parameters described within this specification.

Adherence to the specifications of the NEEA Quality Level (QL) 2 and QL1 lidar data ensures that point data and derivative products are suitable for 3DEP and the standard national DEM available through The National Map. The 3DEP goal to fully realize the benefits documented in the NEEA report (Dewberry, 2012) depends on the ability to manage, analyze, and exploit a lidar dataset spanning the Nation; the vast quantity of lidar data requires these functions be handled through computerized, machine-driven processes that will require uniformly formatted and organized data. Presidential Executive Order 13642, "Making Open and Machine Readable the New Default for Government Information," requires agencies to implement an Open Data Policy, which makes U.S. Government data easily accessible and usable (Obama, 2013). Adherence to these specifications ensures that all data providers handle the source point data in a uniform manner and consistently deliver the point data to the USGS in clearly defined formats.

Purpose and Scope

The USGS intends to use this specification to acquire and procure lidar data and to create consistency across all USGS–NGP and partner-funded lidar collections, in particular those that support the standard national DEM available through The National Map and 3DEP.

This base specification covers four different data QLs and defines minimum parameters for acceptance of the acquired lidar data for each QL. Local conditions in any given project, specialized applications for the data, or the preferences of cooperators may mandate more stringent requirements. In these circumstances, the USGS may support or require the collection of more detailed, accurate, or value-added data. A list of common upgrades to the minimum requirements defined in this specification is provided in appendix 1. Local conditions may also prevent a given collection from meeting these specifications (for example, swamps and marshes, or extremely dense vegetation and closed canopies). 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 by the USGS–NGP. To the highest degree possible, such variances or the expectation of them should be identified prior to issuance of a task order or contract and included within those documents.

The section "Revision History" summarizes the changes between the original version of this specification (version 1.0) and subsequent revisions (versions 1.1, 1.2, and 1.3).

Applicability

These specifications and guidelines are applicable to lidar data and deliverables supported in whole or in part with financial or in-kind contributions by or for the NGP or 3DEP. This specification is not applicable outside the NGP and 3DEP unless explicitly adopted and required by another program or agency.

Maintenance Authority

The USGS–NGP is the maintenance authority for this specification.

Requirement Terminology

Individual requirements are captured throughout this specification as bullet point, "shall" or "will" statements:

- A "shall" statement means that the requirement is to be met in all cases.
- A "will" statement indicates that the requirement is expected to be met wherever possible, but exceptions to implementation may exist.

Background

The USGS–NGP has cooperated in the collection of many lidar datasets across the Nation for a wide array of applications. In the past, 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. These difficulties made the need for a single base specification apparent, particularly one that defined minimum collection parameters and a consistent set of deliverables.

In 2009, the American Recovery and Reinvestment Act (ARRA) provided supplementary funding for The National Map, much of which was targeted for lidar data collection. The increased rate of lidar acquisition highlighted the imperative need for a single data specification to ensure consistency and improve data utility. Although ARRA funding prompted the initial development of a lidar specification, the requirements were always intended to remain durable beyond ARRA-funded NGP projects.

The inception of 3DEP after the completion of the NEEA reinforced the need for a single data specification. Funded cooperatively by numerous State and Federal partners, 3DEP is a national elevation program led by the USGS. This program has been designed to meet the mission-critical data needs of 3DEP partners and other users. The 3DEP goal for lidar data is to produce full national coverage at QL2 or better within 8 years for the conterminous United States (CONUS) and Hawaii, with Alaska being mapped at QL5 using other technologies. Products derived from 3DEP data would be available for the high-priority needs of partners and other users, who could also use the original data to create their own products and services.

In addition, 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, the USGS–NGP may grant waivers of any part or all of this specification, with properly documented justification supporting the need for the variance. In some cases, based on specific topography, land cover, intended application, or other factors, the USGS–NGP may call for requirements more, or less, rigorous than those defined in this specification. For any given collection, technical alternatives that enhance the data or associated products are encouraged, may be submitted with any proposal, and will be given due professional consideration by the USGS–NGP.

Revision History

As lidar technology, techniques, applications and products continue to evolve rapidly, periodic updates to the LBS are also required to maintain its relevance and utility to the USGS and the public. A summary of the most notable changes in each revision follows.

Version 1.1

1. For clarification, numerous sections of the specification were editorially revised and there was minor reorganization of the document.

2. Concurrently with USGS development of the LBS version 1.1, the American Society of Photogrammetry and Remote Sensing (ASPRS) developed the "Positional Accuracy Standards for Digital Geospatial Data" (American Society of Photogrammetry and Remote Sensing [ASPRS], 2014). Glossary definitions in the LBS were updated to align with those in ASPRS (2014) and other industry publications, and several new definitions were added. Notable among these are the following:

   - aggregate nominal pulse density (and spacing)
   - bridge and culvert
   - vegetated vertical accuracy (VVA) and nonvegetated vertical accuracy (NVA)
   - percentile

3. With regard to elevation data, the new standards redefine how elevation accuracy is described and reported, and although any accuracy could be its own accuracy class, a number of specific common classes are explicitly defined. These new ASPRS standard classes are slightly different from those defined by the previous ASPRS standards. Earlier accuracy classes were the basis for the NEEA QL definitions; therefore, the QL accuracy definitions were adjusted to match the new ASPRS classes and to eliminate confusion about accuracy requirements as 3DEP moves forward. Another QL, QL0, was added as a placeholder for the higher-quality data anticipated with future advances in lidar technology. The requirements stated for QL0 are somewhat arbitrary and are subject to change in future revisions of this specification. The changes relevant to lidar data QLs in this revision of the specification were as follows:

   - QL0 was added with accuracy of 5.0-centimeter (cm) vertical linear root mean square error in the *z* direction ($RMSE_z$) and density of at least 8 pulses per square meter (pls/m^2). This aligns with the ASPRS 5-cm vertical accuracy class.
   - QL1 accuracy was changed from 9.25-cm $RMSE_z$ to 10.0-cm $RMSE_z$. This does not correspond directly to any ASPRS accuracy class; it is a hybrid of QL2 accuracy and QL0 pulse density.
   - QL2 accuracy was changed from 9.25-cm $RMSE_z$ to 10.0-cm $RMSE_z$. This aligns with the ASPRS 10-cm vertical accuracy class. QL2 pulse density remains unchanged at 2 pls/m^2.
   - QL3 accuracy was changed from 18.5-cm $RMSE_z$ to 20.0-$RMSE_z$ and density was changed from 0.7 pls/m^2 to 0.5 pls/m^2. This aligns with the ASPRS 20-cm vertical accuracy class.

4. In addition, to align with the new ASPRS accuracy standards, accuracy reporting requirements were defined as based on NVA and VVA. These two classes replaced the previously used fundamental, supplemental, and consolidated vertical accuracy (FVA, SVA, and CVA, respectively) classes.
5. The new ASPRS standards include recommendations tying the quantity of vertical accuracy check points required for a project to the areal extent of the project. This revision of the specification required adherence to these recommendations.
6. QL2 was established as the minimum required QL for new USGS–NGP lidar data collections.
7. Relative accuracy requirements for lidar data, within swath (intraswath) and between overlapping swaths (interswath), were refined and established for each QL. A more detailed methodology for assessing and reporting these metrics was provided.
8. Lidar data delivery is now required in LAS specification version 1.4–R13 (ASPRS, 2011), point data record format (PDRF) 6, 7, 8, 9, or 10. Proper use of the overlap and withheld bit flags is required.

9. The block of lidar specific metadata tags recommended in the previous version of this specification was modified to reflect the other updates to the specification. The

inclusion of this block is now required in all lidar data eXtensible Markup Language (XML) metadata files.

10. The 2-gigabyte (GB) limit on swath file size was removed, although the method for splitting large swath files remains in the specification for use in situations where a data producer needs to produce smaller files.
11. The test area for assessing classification accuracy was corrected from 1 kilometer square to 1 square kilometer.
12. Two additional point classification type requirements were defined:
    - Class 17, Bridges
    - Class 18, High Noise
13. Anticipating that projects will more frequently use multiple coverage collection (for example, overlap greater than 50 percent) to achieve the higher pulse density required, terminology and requirements for this data organization were added.
14. Requirements for datum and coordinate reference systems were refined and clarified.
15. Development and delivery of breaklines were required for all hydro-flattened waterbodies, regardless of the methodology used by the data producer for hydro-flattening.
16. Requirements and guidelines for flightline overlap and scan angle limits were removed. Data producers were cautioned that more rigorous attention will be paid to gaps in and the relative accuracy of the point data.

Version 1.2

1. For clarification, the publication was modified to omit versioning from the main title. No changes were made to the content of the specification.

Version 1.3 (this document)

1. The requirement for delivery of raw, unclassified swath data has been removed.
2. The requirement for XML metadata files for the overall project and for individual lifts has been removed.
3. A requirement to use Geoid12b to convert from ellipsoid heights to orthometric heights has superseded Geoid12a.
4. A requirement that specific coordinate reference system (CRS) information for all projects be agreed upon prior to collection has been added.
5. A requirement for vertical CRS information has been added.
6. A requirement to include the geoid model as part of the vertical CRS name has been added.
7. A requirement to represent horizontal and vertical CRS information as a compound CRS has been added.
8. A requirement that delivered raster elevation files must contain complete and correct georeference information for horizontal and vertical systems, including geoid model used, has been added.
9. A requirement for horizontal accuracy reporting has been added.
10. A requirement for delivery of ancillary products used to support processing of the lidar dataset has been added.
11. A requirement for an attributed polygon feature class representing individual swath boundaries has been added.
12. A clarification on the well-known text (WKT) representation of CRS has been added.
13. A clarification on intensity normalization has been added.
14. A clarification on handling of multiple CRS records in LAS files has been added.
15. A clarification on file source identifier (ID) for tiled LAS files has been added.
16. A clarification of the difference between overlap and overage has been added.
17. A clarification on the identification of overage (overlap) points has been added.
18. A clarification on requirements for the use of overlap and withheld point flags has been added.
19. A clarification on how model key points shall be identified using the LAS key point bit flag has been added.
20. The recommended process for assessing intraswath relative accuracy (repeatability, precision) has been refined to normalize for the natural slope.
21. The recommended process for assessing interswath relative accuracy has been limited to areas with less than (<) 10-degree slope.
22. The maximum limits for interswath differences have been removed.
23. A prohibition on duplication of points within a project has been added.
24. The classification code for “Ignored Ground” (typically used for breakline proximity) has been changed from 10 to 20 to correct the conflict with the ASPRS defined code for “Rail.”
25. A classification code for “Snow” (21) has been added.

26. A classification code for “Temporal Exclusion” (22) has been added.
27. Definitions of swath types have been added to the “Glossary” section.
28. Guidelines for breakline collection, compliant with a newly added EleHydro data dictionary have been added.
29. All references to the National Elevation Dataset (NED) have been changed to “the standard national DEM available through The National Map.” The names “National Elevation Dataset” and “NED” are no longer used for data collected and processed for The National Map or 3DEP.

Collection

Perhaps more than other remote sensing technologies, lidar collection parameters are highly dependent on the environment of the project area. Terrain, land use, vegetative cover, degree of urbanization, airspace control, and numerous additional factors can dictate different flight envelopes, instrument settings, data density, swath overlap, and many more parameters from project to project. Although these variations must be accepted, this section defines a number of collection requirements that must be met to achieve the consistent national lidar collection at the heart of 3DEP.

Collection Area

The defined project area (DPA) shall be buffered by a minimum of 100 meters (m) to create a buffered project area (BPA). Data collection is required for the full extent of the BPA.

For all products to be consistent to the limit of the DPA, all products shall be generated to the full extent of the BPA. Because data and products are generated under contract for the complete BPA, they shall also be delivered to the customer. Data and products in the buffer zone (the area between the DPA and the BPA) will not be tested for any quality requirement. Control points may be located in the buffer zone; all check points shall be located in the DPA.

Quality Level

The minimum acceptable QL for 3DEP collections is QL2, as defined in this specification. *See* tables 1–6 (at the back of the report) for detailed QL requirements.

Multiple Discrete Returns

Deriving and delivering multiple discrete returns is required in all conventional lidar data collection efforts. Data collection shall be capable of at least three returns per pulse. Full waveform collection is acceptable and is promoted; however, full waveform data are regarded as supplemental information.

Intensity Values

Intensity values are required for each multiple discrete return. The values recorded in the LAS files shall be normalized to 16 bit, as required by the LAS specification version 1.4–R13 (ASPRS, 2011). It warrants re-emphasis that intensity normalization is strictly linear. Common image stretches (minimum-maximum, standard deviations, percent clip, histogram, and so forth) are expressly forbidden.

Nominal Pulse Spacing

The term nominal pulse spacing (NPS) has been widely used across the industry for decades; the counterpart term, nominal pulse density (NPD), came into use when collection densities began to fall below 1 pls/m^2. These terms were used by instrument manufacturers and data producers to describe instrument performance and collection targets, and, in these contexts, the terms almost always refer to single swath, first-return-only collection. For much of the history of lidar use, most collections were planned and executed as single coverage flight missions; thus, these terms also were used by data consumers, whose interests are naturally focused on the net result of a collection.

The trend towards achieving the specified NPS for a project through multiple flight passes, overlap greater than 50 percent, multichannel instruments, and multiple instruments on a single collection platform has expanded the industry’s options and flexibility in designing lidar collection missions. Complexity and confusion have also been added to assessment and reporting standards. The net pulse density of a collection may be several times greater than the planned density of a single swath. The terms “NPS” and “NPD” can have quite different meanings to different members of the lidar community.

In this specification, the terms “NPS” and “NPD” will continue to reference single instrument, single swath, first-return-only lidar data. Maintaining this terminology provides a consistent and understandable metric for communication regarding data collection.

Multiple channels of data from a single instrument are regarded as a single swath. In this sense, a single instrument would be regarded as one in which all channels meet the following criteria:

- they share fundamental hardware components of the system, such as global positioning system (GPS), inertial measurement unit (IMU), laser, mirror or prism, and detector assembly;
- they share a common calibration or boresighting procedure and solution; and

- they are designed and intended to operate as a single-sensor unit.

Assessment and reporting of the NPS are made against single swath, single instrument, first-return-only data, including only the geometrically usable part of the swath and excluding acceptable data voids. The NPS can be predicted using flight planning software or empirically calculated by delineating a 1 square kilometer (km^2) (or greater) polygon that is representative of the overall pulse density of the swath. The NPS is the square root of the average area per point (the area of the polygon divided by the number of points it contains). These two techniques will produce slightly different values. The NPS is largely regarded as a mission design and planning metric.

Higher net densities of lidar point measurements are being achieved more often by flying multiple passes of the lidar instrument over the project area or flying with large amounts (greater than [>] 50 percent) of overlap between swaths, creating a need for a new term to describe total pulse density without being confused with NPS and NPD. This specification will use the terms aggregate nominal pulse spacing (ANPS) and aggregate nominal pulse density (ANPD) to describe the net overall pulse spacing and density, respectively. On projects designed to achieve the ANPS through single coverage, ANPS and NPS are equal.

Like NPS, ANPS includes only the geometrically usable part of the swaths, excludes acceptable data voids, and can be empirically calculated using the method described above for NPS. Conversion between ANPS and ANPD is the same as for NPS and NPD.

The required ANPS and ANPD by QL are listed in table 1. Dependent on the local terrain and land cover conditions in a project, a greater pulse density may be required on specific projects.

Data Voids

Data voids in lidar are gaps in the point data coverage caused by surface absorbance, scattering, or refraction of the lidar pulse (that is, where laser pulse energy is not returned to the sensor), instrument or processing anomalies or failure, obstruction of the lidar pulse, or improper collection because of flight plans. A data void is considered to be any area greater than or equal to $(4 \times ANPS)^2$, which is measured using first returns only. Data voids within a single swath are not acceptable, except in the following circumstances:

- where caused by waterbodies;
- where caused by areas of low near infrared reflectivity, such as asphalt or composition roofing;
- where caused by lidar shadowing from buildings or other features; or
- where appropriately filled in by another swath.

For projects designed to achieve the required ANPS through multiple coverage, the entire BPA shall be covered with the designed number of swaths. Areas meeting the size threshold defined above for single coverage that are not covered by the *designed* number of swaths are data voids. For example, consider a project designed to achieve a minimum required ANPD of 2 pls/m^2, using an NPD of 1.2 pls/m^2 and 55-percent overlap. During preprocessing, the outer edges of the swaths are determined to be geometrically unreliable, those points are tagged as “Withheld,” and the usable width of the swath is narrowed. In addition, normal variations in flight stability and the resulting undulations in the linearity of the swath edges then leave areas between the overlaps where the surface is covered by only one swath. Because the design of the project was for double coverage, the areas covered by only one swath and exceeding the size limit defined above are regarded as data voids. Graphic examples of these data voids are shown in figures 1–3 (at the back of the report). The project will be rejected unless these areas are later augmented with fill-in swaths.

Spatial Distribution and Regularity

The process described in this section relates only to regular and uniform point distribution. The process does not relate to, nor can it be used for, the assessment of NPS, ANPS, or data voids. The spatial distribution of geometrically usable points will be uniform and regular. Although lidar instruments do not produce a regular grid of points, collections will be planned and executed to produce an aggregate first return point data that approaches a uniform, regular lattice of points, rather than a collection of widely spaced, high-density profiles of the terrain. The regularity of the point pattern and density throughout the dataset is important and will be assessed by using the following method:

- Assess only nonwithheld, first return points of a single File Source ID.
- Exclude acceptable data voids previously identified in this specification.
- Generate a density raster from the data with a cell size equal to twice the design ANPS.
- Populate the raster using a count of points within each cell.
- Ensure that at least 90 percent of the cells in the grid contain at least one lidar point.

The USGS–NGP may allow lower passing thresholds for this requirement in areas of substantial relief where maintaining a regular and uniform point distribution is impractical.

Collection Conditions

Conditions for collection of lidar data will follow these guidelines:

- Atmospheric conditions shall be cloud and fog free between the aircraft and ground during all collection operations.
- Ground conditions will be snow free. Very light, undrifted snow may be acceptable with prior approval.
- Ground conditions shall be free of extensive flooding or any other type of inundation.

Although leaf-off vegetation conditions are preferred, many factors beyond human control may affect dormant conditions at the time of any collection; therefore, the USGS–NGP only requires that penetration to the ground be adequate to produce an accurate and reliable bare-earth surface for the prescribed QL. Collections planned for leaf-on collections shall be approved by the USGS–NGP/3DEP prior to issuance of a task order or contract.

Data Processing and Handling

As noted in the “Introduction” section, 3DEP is keenly interested in the utility of lidar data beyond development of high resolution DEMs. As a nationwide data program, it is also critically important that all 3DEP lidar data holdings are as consistent as possible. While there are factors on any project that may require different collection parameters, the most problematic variations between collections result from different processing techniques, tools, and general approaches to data production across the industry. These variations can be better controlled to produce more consistent and usable lidar data across all collections. Without dictating specific tools or workflows, this section describes best practices for data production to ensure the quality and compatibility of all 3DEP lidar data.

American Society for Photogrammetry and Remote Sensing LAS File Format

All processing will be carried out with the understanding that all point deliverables are required to be in LAS format, version 1.4, using PDRF 6, 7, 8, 9, or 10. Data producers are encouraged to review the LAS specification version 1.4–R13 in detail (ASPRS, 2011).

Full Waveform

If full waveform data are recorded during collection, the waveform packets shall be delivered. LAS deliverables, including waveform data, shall use external auxiliary files with the extension .wdp to store waveform packet data. *See* LAS specification version 1.4–R13 (ASPRS, 2011) for additional information.

Time of Global Positioning System Data

The time of GPS data shall 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 10^9. The encoding tag in the LAS header shall be properly set. *See* LAS specification version 1.4–R13 (ASPRS, 2011) for additional information.

Datums

Geospatial data must be tied to a clearly and precisely defined reference, or datum. Over time, the tools and techniques used to geometrically define datums become more accurate and precise, and datum definitions change accordingly. Without knowing the specific datum and its adjustments of a dataset, relating it to the physical world or other spatial datasets becomes unreliable. To maximize the usability of 3DEP lidar and elevation products, all data collected shall be tied to the datums listed below:

1. For the CONUS, unless otherwise specified by the user and agreed to in advance by the USGS–NGP:
    - The horizontal datum for latitude and longitude and ellipsoid heights will be the North American Datum of 1983 (NAD 83) using the most recent NGS-published adjustment (currently NAD 83, epoch 2010.00, realization of 2011).
    - The vertical datum for orthometric heights will be the North American Vertical Datum of 1988 (NAVD 88).
    - The geoid model used to convert between ellipsoid heights and orthometric heights will be the latest hybrid geoid model of NGS, supporting the latest realization of NAD 83 (currently [2017] Geoid12b model).
2. For Alaska, American Samoa, Commonwealth of the Northern Mariana Islands, Guam, Hawaii, Puerto Rico, U.S. Virgin Islands, and other areas:
    - USGS–NGP and all collection partners shall agree to and specify horizontal and vertical datums, ellipsoids, and geoids in advance of data collection.

Coordinate Reference System

Lidar data and all related or derived data and products shall be processed and delivered in a single CRS agreed upon in advance of data collection by the USGS–NGP and all project partners and cooperators. The complete CRS definition and its WKT representation, both horizontal and vertical, shall be documented as part of the agreement. In all cases, the CRS used shall be recognized and published by the European Petroleum Survey Group (EPSG) and correctly recognized by current industry standard geographic information system (GIS) software applications.

Each project shall be processed and delivered in a single CRS, except in cases where a project area covers multiple CRSs such that processing in a single CRS would introduce unacceptable distortions in part of the project area. In such cases, the project area is to be split into subareas appropriate for each CRS. Each subarea shall be processed and delivered as a separate subproject with its own CRS. All requirements for a single project will apply to each subproject, notably the inclusion of the required buffer area and delivery of DPA and BPA boundaries. The DPA boundaries of adjacent subareas shall have topologically coincident boundaries along their common borders. The individual DPA boundaries are necessary to ensure that the adjacent subarea datasets can subsequently be merged in a single CRS without introducing duplicate points. For each project or subarea, all spatial data within the area shall be in the same CRS.

Well-Known Text

In the late 1990s, the European Petroleum Survey Group (EPSG) developed and published the EPSG Geodetic Parameter Dataset, containing definitions of many of the geodetic, projection, and coordinate reference systems in use throughout the world. The database is updated semi-annually and over the years has become the authoritative global source for geodetic information. In 2005, the EPSG was absorbed by the International Association of Oil and Gas Producers (IOGP) as its Geodesy Subcommittee, which continues maintenance and distribution of the EPSG database.

In 2001, the Open Geospatial Consortium (OGC) developed and published a specification (Open Geospatial Consortium [OGC], 2001) to define coordinate reference systems (CRS) that was both human- and machine-readable, and was based on the definitions held in the EPSG database. This specification is commonly referred to as “WKT-1”. In 2007, the International Standards Organization (ISO) published a similar specification (ISO, 2007) for WKT representation of CRSs.

In 2015, the OGC and ISO jointly revised and harmonized their respective CRS WKT specifications and each published the new document (OGC, 2015; also ISO, 2015). Awareness and adoption of this specification is still inconsistent across the industry, making its adoption in the LBS premature at this time. Data producers and software developers should be aware that the specification will become a requirement in a future revision of the LBS.

According to the LAS specification version 1.4–R13 (ASPRS, 2011):

> “For definition of WKT, we refer to Open Geospatial Consortium (OGC) specification “OpenGIS coordinate transformation service implementation specification” revision 1.00 released 12 January 2001, section 7 (coordinate transformation services spec). This specification may be found at www.opengeospatial.org/standards/ct. As there are a few dialects of WKT, please note that LAS is not using the “ESRI WKT” dialect, which does not include TOWGS84 and authority nodes.”

Thus, CRS information in LAS files shall use WKT as defined in OGC (2001). All other WKT specifications, including Esri, ISO, and OGC (2015) are expressly forbidden.

The CRS WKT may be recorded in either a variable length record (VLR) or an extended variable length record (EVLR) at the discretion of the data producer. The CRS record shall contain no whitespace unless enclosed within double quotation marks. The CRS record shall contain no carriage returns (CRs), line feeds (LFs), or new lines (NLs), or any other special, control, or nonprintable characters.

For verification or generation of properly formatted WKT, the USGS recommends the use of the gdalsrsinfo (http://www.gdal.org/gdalsrsinfo.html) tool. gdalsrsinfo is a command line tool that can be downloaded and installed using the OSGeo4W installer (https://trac.osgeo.org/osgeo4w/). The following command will produce WKT that the USGS considers to have valid form:

$ gdalsrsinfo -o wkt “EPSG:<code>”

However, the USGS recommends four exceptions to the gdalsrsinfo output:

- gdalsrsinfo adds an `EXTENSION[]` tag to capture geoid information in the `VERT_DATUM[]` section that is not defined in the WKT specification. Data providers shall remove the `EXTENSION[]` tag if it is shown.
- In cases where the datum name output from gdalsrsinfo differs from that listed in the EPSG Registry database (http://www.epsg-registry.org), the USGS would prefer that the name be changed to match the EPSG Registry; however, the GDAL output will be accepted. For example, EPSG:1116 is named “NAD83_National_Spatial_Reference_System_2011” in the output from GDAL but the name on EPSG Registry is “NAD83 (National Spatial Reference System 2011)” and the only listed alias is “NAD83(2011)”
- For all projected coordinate systems, the USGS recommends WKT (OGC, 2001) default values: `AXIS[“X”,EAST], AXIS[“Y”,NORTH];` however, the GDAL output (“`Easting`” and “`Northing`” rather than “`X`” and “`Y`”) will be accepted.

- gdalsrsinfo and EPSG outputs use "`metre`" instead of the U.S. convention "`meter`." Either spelling is acceptable to the USGS.

The USGS recognizes that the GDAL tool is not a rigorous standards-based solution, but it is a mutually convenient open source tool suitable for 3DEP purposes at this time. Following are the USGS directions for specific WKT format and content:

- The vertical CRS shall be included in the CRS.
- The geoid name shall be appended to the `VERT_CS[]` name field. For example:
  - `VERT_CS["NAVD88 height (ftUS) - Geoid12b"]`.
- Horizontal and vertical CRS shall be wrapped within a `COMPD_CS`.
- The EPSG `AUTHORITY[]` tag shall not be included for the compound coordinate system.
- User-defined entities will not be allowed for capturing geoid information in the WKT (for example, `GEOID_MODEL[]`). These nonstandard entity entries are not consistently machine readable.
- All elements of the CRS record shall include the EPSG `AUTHORITY[]` entry and a valid EPSG code, except where no EPSG code exists for the element or where otherwise excluded from this requirement within this specification.
- A given LAS file may contain any number of CRS entries, as VLRs and (or) EVLRs in any combination, as WKT and (or) GeoTIFF in any combination, regardless of the PDRF, provided that:
  - ALL entries shall be tagged as "Superseded"—EXCEPT for the single valid entry to be used. *See* LAS specification version 1.4–R13 (ASPRS, 2011) for further details.
  - The single valid entry shall be compliant WKT (OGC, 2001).
  - The global encoding bit for CRS shall be set to 1.

The geoid model used to convert elevations from the ellipsoid to orthometric heights shall also be identified in the `<lidar><ldrinfo><ldrgeoid>` tag within the Federal Geographic Data Committee (FGDC) metadata files. The NGS model filename shall be recorded (for example, `<ldrgeoid>g2012Bu0.bin</ldrgeoid>`).

Units of Reference

All references to the units of measure "Feet" and "Foot" shall specify "International," "Intl," "U.S. Survey," or "US."

File and Point Source Identification

At the time of its creation and prior to any further processing, each swath shall be assigned a unique file source ID, and each point within the swath shall be assigned a point source ID equal to the file source ID. The point source ID on each point shall be persisted unchanged throughout all processing and delivery. The file source ID for tiled LAS files shall be set to 0. *See* LAS specification version 1.4–R13 (ASPRS, 2011).

Positional Accuracy Validation

Prior to classification and development of derivative products from the point data, the absolute and relative vertical accuracy of the point data shall be verified. A detailed report of the validation processes used shall be delivered.

Absolute Horizontal Accuracy

The nature of lidar data makes it difficult to assess absolute horizontal accuracy as one would with imagery or compiled planimetric data. Guidance on how absolute horizontal accuracy can be estimated and reported, based on the error budget of the instrumentation and operational parameters, can be found in ASPRS (2014). The horizontal accuracy of each lidar project shall be reported using the form specified by the ASPRS (2014):

> "This data set was produced to meet ASPRS "Positional Accuracy Standards for Digital Geospatial Data" (2014) for a ___ (cm) RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- ___ cm at a 95% confidence level."

Relative Vertical Accuracy

Relative vertical accuracy refers to the internal geometric quality of a lidar dataset without regard to surveyed ground control. Two primary factors need to be considered in lidar data vertical accuracy:

- smooth surface precision (intraswath), and
- overlap consistency (interswath).

Intraswath Precision

The precision of lidar is the quantified assessment of variations in measurements of a surface that, under ideal theoretical conditions, would be without variation. Precision is evaluated to confirm that the lidar system is performing properly and without gross internal error that may not be otherwise apparent.

The precision of a lidar dataset could be measured simply by calculating the range of *z* values of lidar points reflected from a perfectly flat, level surface. In the natural world, however, such a surface does not exist. Relatively level pavement (such as an empty parking lot) or a large flat roof are often the best surrogates available, though these also have natural variations in elevation that must be considered. The use of a raster-based analysis constrains the elevation range measurements to the points within the small area of each cell, limiting the amount of natural elevation variation. It was believed that this approach would limit natural elevation variation effectively; however, it was subsequently determined that even with cell sizes as small as 2 m, enough natural variations can substantially skew the assessment. Additional steps must be taken to account for natural elevation variations.

Knowing the slope and size of each cell allows the natural elevation variation within the cell to be estimated. Subtracting this value from the range of lidar measurements within the cell isolates the variability of the lidar measurements, or the lidar's precision. Although the resulting value is merely an estimate, it is accurate enough for subjective evaluation of the data. Precision will be calculated using the following method:

$$Precision = Range - (Slope \times Cellsize \times 1.414) \quad (1)$$

where:
Precision, *Range*, and *Slope* are rasters (square cells assumed);
Range is the difference between the highest and lowest lidar points in each pixel;
Slope is the maximum slope of the cell to its 8 neighbors, expressed as a decimal value, calculated from the minimum elevation in each cell; and
CellSize is the edge dimension of the cell.
1.414 is the factor to compute the diagonal dimension of the pixel.

CellSize is set to the ANPS, rounded up to the next integer, and then doubled:

$$Cellsize = CEILING(ANPS) \times 2 \quad (2)$$

where:
CEILING is a function to round ANPS up to the next integer.

Assessment of precision will be made on hard surfaced areas (for example, parking lots or large rooftops) containing only single return lidar points. Sample areas will be approximately 100 pixels. To the degree allowed by the data and project environment, multiple sample areas representing the full width of the swath(s) (left, center, and right) will be examined. Multiple single swaths from a single lift may be used if needed to sample the full swath width. At a minimum, precision shall be assessed against for each lift of each aircraft/instrument combination used on the project. Additional areas may be checked at the discretion of the USGS–NGP.

Each test area will be evaluated using a signed difference raster with a cell size equal to the ANPS, rounded up to the next integer, then doubled (*Cellsize = CEILING(ANPS)* × 2). The difference rasters will be statistically summarized to verify that root mean square difference in the *z* direction ($RMSD_z$) values do not exceed the limits set forth in table 2 for the QL of information that is being collected. Precision shall be reported by way of a polygon shapefile delineating the sample areas checked and attributed with the following and using the cells within each polygon as sample values:

- Minimum slope-corrected range (numeric)
- Maximum slope-corrected range (numeric)
- $RMSD_z$ of the slope-corrected range (numeric)

Interswath (Overlap) Consistency

Overlap consistency is a measure of the geometric agreement of two overlapping swaths, and a fundamental measure of the quality of the calibration or boresight adjustment of the data in each lift. It is of particular importance because the match between the swaths of a single lift is a strong indicator of the geometric quality of the overall dataset, establishing the quality and accuracy limits of all downstream data and products. The principles used with swaths can also be applied to the overlap between lifts and projects as well.

Overlap consistency will be assessed at multiple locations within overlap in nonvegetated areas of only single returns. Assessment is limited to areas of <10-degree slope. To the degree that the data allow, test areas should be located such that the full width of the overlap is represented. The overlap areas that will be tested are those between the following:

- adjacent, overlapping parallel swaths within a project;
- cross-tie swaths and a sample of intersecting project swaths in both flight directions; and
- adjacent, overlapping lifts.

Each overlap area will be evaluated using a signed difference raster with a cell size equal to the ANPS, rounded up to the next integer, then doubled (*Cellsize = CEILING(ANPS)* × 2). The difference rasters will be statistically summarized to verify that $RMSD_z$ values do not exceed the limits set forth in table 2 for the QL of information that is being collected. As with precision, the interswath consistency shall be reported by way of a polygon shapefile delineating the sample areas checked and attributed with the following and using the cells within each polygon as sample values:

- Minimum difference in the sample area (numeric)
- Maximum difference in the sample area (numeric)
- $RMSD_z$ of the sample area (numeric)

Check Points

In the "Positional Accuracy Standards for Digital Geospatial Data" (ASPRS, 2014) the required number of check points for vertical accuracy assessment is tied to the areal extent of the project. This requirement has also been adopted in the LBS. Data producers are encouraged to carefully review the new and revised requirements in the ASPRS standards.

Check points for NVA assessments shall be surveyed in clear, open areas (which typically produce only single lidar returns) devoid of vegetation and other vertical artifacts (such as boulders, large riser pipes, and vehicles). Ground that has been plowed or otherwise disturbed is not acceptable. The same check points may be used for NVA assessment of the point data and DEM.

Check points for VVA assessments shall be surveyed in vegetated areas (typically characterized by multiple return lidar). Although the nature of vegetated areas makes absolute definition of a suitable test area difficult, these areas will meet the requirements below.

Suitable areas for check point survey are defined as having a minimum homogeneous area of $(ANPS * 5)^2$, with less than one-third of the required $RMSE_z$ deviation from a low-slope (<10 degrees) plane. In land covers other than forested and dense urban, the tested point will have no obstructions above 15 degrees over the horizon. All tested locations will be photographed showing the position of the survey tripod and the ground condition of the surrounding area. Additionally, control points used in the calibration process for data acquisition shall not be used as check points. Check points shall be an independent set of points used for the sole purpose of assessing the vertical accuracy of the project.

As stated in the "National Standards for Spatial Data Accuracy" (Federal Geographic Data Committee, 1998) and reiterated in ASPRS (2014), it is unrealistic to prescribe detailed requirements for check point locations because many unpredictable factors will affect field operations and decisions, and the data producer often requires the freedom to use their best professional judgment. The quantity and location of check points shall meet the following requirements, unless alternative criteria are approved by the USGS–NPG in advance:

1. The ASPRS-recommended total number of check points for a given project size shall be met.
2. The ASPRS-recommended distribution of the total number of check points between NVA and VVA assessments shall be met.
3. Check points within each assessment type (NVA and VVA) will be well-distributed across the entire project area; *see* "Glossary" section at the end of this specification for a definition of "well-distributed."
4. Within each assessment type, check points will be distributed among all constituent land cover types in approximate proportion to the areas of those land cover types (ASPRS, 2014).

Absolute Vertical Accuracy

Absolute vertical accuracy of the lidar data and the derived DEM will be assessed and reported in accordance with ASPRS (2014). Two broad land cover types shall be assessed: vegetated and nonvegetated. Federal Emergency Management Agency (2003) identifies seven land cover types; National Digital Elevation Program (2004) and ASPRS (2004) reiterate the first five of those types. The way in which each of the seven classes was reported under the previous standards and how they are reported under the new ASPRS standards and by this specification are shown in table 3. Three absolute accuracy values shall be assessed and reported:

1. NVA for the point data
2. NVA for the DEM
3. VVA for the DEM

The minimum NVA and VVA requirements for all data, using the ASPRS methodology, are listed in table 4. Both the NVA and VVA required values shall be met.

The unclassified point data shall meet the required NVA before further classification and processing. NVA for the point data is assessed by comparing check points surveyed in clear, open, nonvegetated areas (which typically produce only single lidar returns) to a triangulated irregular network (TIN) constructed from the single return lidar points in those areas. NVA and VVA for the DEM are assessed by comparing check points to the final bare-earth surface.

The minimum required thresholds for absolute and relative accuracy may be increased by the USGS–NGP when any of the following conditions are met:

- A demonstrable, substantial, and prohibitive increase in cost is needed to obtain this accuracy, which is often the case in heavily vegetated project areas.
- An alternate specification is needed to conform to previously contracted phases of a single larger overall collection effort such as for multiyear statewide collections.
- The USGS–NGP agrees that the use of an alternate specification is reasonable and in the best interest of all stakeholders.

Use of the LAS Withheld Bit Flag

Outliers, blunders, geometrically unreliable points near the extreme edge of the swath, and any other points the data producer deems unusable are to be identified using the withheld bit flag, as defined in LAS specification version 1.4–R13 (ASPRS, 2011). The withheld bit flag is primarily used to denote points identified during preprocessing or through automated postprocessing routines as geometric blunders.

Noise points subsequently identified during manual classification and quality assurance/quality control (QA/QC) are typically assigned the appropriate standard LAS classification values for noise—class 7 is used for low noise and class 18 is used for high noise. Noise classes are primarily used to denote points that are valid but not earth-bound (for example, birds) or spurious (for example, artificially induced deviations in elevation at or near land/water interfaces).

Use of the LAS Overage (Overlap) Bit Flag

The LAS specification version 1.4–R13 (ASPRS, 2011) includes a new overlap flag. Although strictly speaking, the term “overlap” would mean all lidar points lying within any overlapping areas of two or more swaths, the overlap bit flag is intended to identify overage points, which are only a subset of overlap points. For more information on the difference between overlap and overage, refer to figures 4–5 (at the back of the report) and the “Glossary” section. Identification of overage points allows their simple exclusion from subsequent processes where the increased density and elevation variability they introduce is unwanted (that is, DEM generation).

For some years, overage points were commonly identified using class 12, precluding other valuable classification (for example, bare-earth, water). The overlap bit flag provides a discrete method to identify overage points while preserving the ability to classify the points in the normal way. Overage points shall be identified using the LAS overlap bit flag in all point data deliverables.

Overage points are described as those points within a given swath that would be excluded when constructing a coverage with a uniform depth of swaths at any location with the project. This uniform coverage is what is often used to construct a DEM or other surface because it prevents variations caused by substantially increased point density in overlap areas. If the dataset is of sufficient quality to produce a uniform DEM without the exclusion of these points (for example, that the presence of denser and less vertically correlated source points are not discernable in the DEM), flagging of overage points is not required, although data of this quality are highly unusual.

Point Classification

The minimum classification scheme required for lidar data is listed in table 5. Additional classes may be required on specific projects. The following requirements apply to point classification:

- All points not identified as withheld shall be properly classified.
- No points in the classified LAS deliverable may remain assigned to class 0.
- Model key points, if calculated, shall be identified using the key point bit flag as defined in LAS specification version 1.4–R13 (ASPRS, 2011). Model key points may, in addition, be identified using class 8 at the discretion of the data producer.
- No classification code or value may be used to identify overage (overlap) points. All overage (overlap) points shall be identified using the overlap bit flag, as defined in LAS specification version 1.4–R13 (ASPRS, 2011).

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

A single nonoverlapping project tiling scheme will be established and agreed upon by the data producer and the USGS–NGP before collection. This scheme will be used for all tiled deliverables:

- The tiling scheme shall use the same coordinate reference system and units as the data.
- The tile size shall be an integer multiple of the cell size for raster deliverables.
- The tiles shall be indexed in x and y to an integer multiple of the x and y dimensions of the tile.
- The tiled deliverables shall edge-match seamlessly and without gaps.
- The tiled deliverables shall conform to the project tiling scheme without added overlap.

Point Duplication

Duplication of lidar points (*x*, *y*, *z*, and *timestamp*) within the project is not acceptable. LAS files containing duplicated points will be rejected. Near duplication (that is, a group of points duplicated but with a slight but consistent spatial offset) will be regarded as duplication.

Deliverables

The USGS requires unrestricted rights to all delivered data and reports as they will be placed in the public domain. This specification places no restrictions on the rights of the data provider to resell data or derivative products. The USGS further requires delivery of all ancillary products collected under the contract that support the processing of the lidar dataset. This includes, but is not limited to, aerial video and imagery, and all metadata associated with those data.

Metadata

The term "metadata" refers to all descriptive information about the project, and metadata includes text reports, graphics, and supporting shapefiles. Product metadata files shall comply with the "Content Standard for Digital Geospatial Metadata" (CSDGM) (FGDC, 1998), which facilitates the development, sharing, and use of geospatial data. Metadata deliverables shall include the following:

- A survey report detailing the collection of all ground survey data, including the following:
    - Control points used to calibrate and process the lidar and derivative data.
    - Check points used to validate the lidar data or any derivative product.
- A collection report detailing mission planning and including detailed flight logs. Flight logs are expected to include:
    - A unique ID for each lift.
    - The take-off and landing times for each lift.
    - The aircraft make, model, and tail number.
    - The instrument manufacturer, model, and serial number.
    - The date of the instrument's most recent factory inspection/calibration.
    - General weather conditions.
    - General observed ground conditions.
    - All inflight disturbances and notable head/tail/crosswinds.
    - All inflight instrument anomalies and any inflight changes in settings.
- A processing report detailing calibration and instrument settings by lift and identified by the lift ID, classification methods, and product generation procedures including methodology used for breakline collection and hydro-flattening (*see* the "Hydro-Flattening" section and appendix 2 for more information on hydro-flattening).
- A QA/QC report, detailing procedures for analysis, accuracy assessment, and validation of the project data, including the following:
    - The expected horizontal accuracy of the lidar data, as described in ASPRS (2014).
    - The assessed relative vertical accuracy of the point data (smooth surface repeatability and overlap consistency). Relative vertical accuracy requirements are listed in table 2.
    - The assessed NVA of the unclassified lidar data in accordance with the guidelines set forth in ASPRS (2014). Absolute vertical accuracy requirements for the unclassified point data using the ASPRS methodology are listed in table 4.
    - The assessed NVA and VVA of the bare-earth surface in accordance with the guidelines set forth in ASPRS (2014). Absolute vertical accuracy requirements using the ASPRS methodology for the bare-earth DEM are listed in table 4.
    - QA/QC analysis materials for the absolute vertical accuracy assessment.
- NOTE: The four reports listed above may be compiled as separate documents, or combined into a single document, at the discretion of the data producer.
- A georeferenced, polygonal representation of the detailed extents of each lidar swath collected, as a GIS layer. The goal is a set of polygons that define the area actually covered by the swaths, not merely the points collected in the swaths.
    - The extents shall be those of the actual coverage of the collected swath, exclusive of peripheral TIN artifacts. Minimum bounding rectangles or simplified rectangles are not acceptable. The boundary will generally follow the overall shape of the swath as defined by the points tagged as Edge of Flightline. Perimeter incursions into the swath, such as those caused by waterbodies, should not be followed.

- Each swath polygon shall be attributed with the following:
  - The Project Name (string format).
  - The Start Date and Time of the swath (date format, minute resolution).
  - The End Date and Time of the swath (date format, minute resolution).
  - The lift's unique ID (string format).
  - The unique File Source ID of the swath (string format).
  - The type of swath: "Project," "Cross-tie," "Fill-in," "Calibration," or "Other" (string format).
- Esri polygon shapefile or geodatabase is required.

- A georeferenced, digital spatial representation of the detailed extents of each delivered dataset.
  - The extents shall be those of the actual lidar source or derived product data, exclusive of peripheral TIN artifacts or raster NODATA areas.
  - A union of tile boundaries or minimum bounding rectangles is not acceptable.
  - For the point datas, no line segment in the boundary will be longer than the four times the ANPS from the nearest lidar point.
  - Esri polygon shapefile or geodatabase is required.
- Product metadata (FGDC compliant, XML format metadata).
  - One XML file is required for each of the following deliverable product groups:
    - Classified point data.
    - Bare-earth DEMs.
    - Breaklines.
    - Any other datasets delivered (digital surface models [DSM], intensity images, height above ground surfaces, and others).
  - Metadata files for individual data files within a deliverable product group are acceptable but are not required.
  - FGDC-compliant metadata shall pass the USGS Metadata Parser (MP) without errors.

A block of lidar-related metadata tags specified by the USGS shall be included in the CSDGM (FGDC, 1998) metadata files for all lidar data deliverables. All tags are required. Tags requiring a numeric value shall not contain text (that is, units) because the required reporting units are defined in the appendix 4. This block was developed so information often provided in reports or in free-text metadata fields can be made machine-discoverable in a predictable location in a single file. The descriptive template of this lidar metadata block is provided in appendix 4 and a completed example is provided in appendix 3.

Classified Point Data

Unless waived through a pre-collection agreement with the NGP and noted clearly in the task order, delivery of classified point data is a requirement for USGS–NGP lidar projects. Classified point data deliverables shall include or conform to the following procedures and specifications:

- All project swaths, returns, and collected points shall be fully calibrated, adjusted to ground, classified, and segmented into tiles. Project swaths exclude calibration swaths, cross-ties, and other swaths not used, and not intended to be used, for product generation.
- LAS Specification version 1.4, PDRF 6, 7, 8, 9, or 10.
- Overage (Overlap) and Withheld flags set as appropriate.
- If collected, waveform data in external auxiliary files with the extension .wdp. *See* LAS specification version 1.4–R13 (ASPRS, 2011) for additional information.
- Correct and properly formatted georeference information as WKT (OGC, 2001) included in all LAS file headers.
- GPS times recorded as Adjusted GPS Time at a precision sufficient to allow unique timestamps for each pulse.
- Intensity values, normalized to 16-bit. *See* LAS specification version 1.4–R13 (ASPRS, 2011) for additional information.
- Tiled delivery, without overlap, using the project tiling scheme.
- Classification, as defined in table 5, at a minimum.

Bare-Earth Surface (Raster Digital Elevation Model)

Delivery of a hydro-flattened bare-earth topographic DEM is a requirement for all USGS–NGP lidar projects. Specific research projects may be exempt from some or all these requirements. Bare-earth surface deliverables shall include or conform to the following procedures and specifications:

- Bare-earth DEM, generated to the limits of the BPA.
- DEM resolution as shown in the table 6.
- An industry-standard, GIS-compatible, 32-bit floating point raster format. Earth Resources Data Analysis System (ERDAS) Imagine (.img) format is preferred.
- DEM data shall be in the same CRS as the lidar data.
- Georeference information in or accompanying each raster file, as appropriate for the file format. This information shall include both horizontal and vertical systems; the vertical system name shall include the geoid model used to convert from ellipsoid heights to orthometric heights.
- Tiled delivery without overlap.
- DEM tiles with no edge artifacts or mismatch. A quilted appearance in the overall DEM surface will be cause for rejection of the entire DEM deliverable, whether the variations are caused by differences in processing quality or character among tiles, swaths, lifts, or other artificial divisions.
- Void areas (for example, areas outside the BPA but within the project tiling scheme) coded using a unique NODATA value. This value will be identified in the appropriate location within the raster file header or external support files (for example, .aux or .xml metadata).
- Hydro-flattening as outlined in the "Hydro-Flattening" section. Depressions (sinks), whether natural or man-made, are not to be filled (as in hydro-conditioning). The methodology used for hydro-flattening is at the discretion of the data producer (refer to appendix 2 for more information on hydro-flattening).
- Bridges removed from the surface (refer to the "Glossary" section for the definition of "bridge").
- Road or other travel ways over culverts remain intact in the surface (refer to the "Glossary" section for the definition of a culvert).
- A report on the assessed absolute vertical accuracy of the bare-earth surface in accordance with the guidelines set forth in ASPRS (2014). Absolute vertical accuracy requirements using the ASPRS methodology for the bare-earth DEM are listed in table 4.
- QA/QC analysis materials used in the assessment of absolute accuracy.

Breaklines

Delivery of all breaklines collected on or used in support of the project is required for USGS–NGP lidar projects. This includes breaklines used for bridge and saddle treatments and any additional breaklines required by project cooperators.

Breaklines representing all hydro-flattened features in a project, regardless of the method used for hydro-flattening, are required for USGS–NGP lidar projects. Specific research projects may be exempt from these requirements with prior approval of the USGS–NGP. Breakline deliverables shall include or conform to the following procedures and specifications:

- Breaklines developed to the limit of the BPA.
- Breaklines delivered in shapefile or file geodatabase formats, as PolylineZ and PolygonZ feature classes, as appropriate to the type of feature represented and the methodology used by the data producer.
- Breakline data shall be in the same CRS as the lidar data.
- Each breakline feature class shall have properly formatted, accurate, and complete georeferenced information stored in the format's standard file system location. Each shapefile shall include a correct and properly formatted .prj file. All CRS information for 3-dimensional (3D) data shall include the vertical reference and identify the geoid model used to convert from the ellipsoid to orthometric heights.
- Breakline data will conform to the requirements defined in the "EleHydro Breakline GIS Data Dictionary" section.
- Breakline delivery may be in a single layer or in tiles, at the discretion of the data producer. In the case of tiled deliveries, all features shall edge-match exactly across tile boundaries in both the horizontal (*x, y*) and vertical (*z*) spatial dimensions. Delivered data shall be sufficient for the USGS to effectively recreate the delivered DEMs using the lidar points and breaklines without substantial editing.

Digital Elevation Model Surface Treatments

Historically, the USGS topo maps and DEMs have been topographic (*see* appendix 2) and appropriate for the development and depiction of contour lines. The character of lidar-based DEMs differs from traditional DEMs derived through stereo photogrammetry, necessitating additional treatment of the lidar-based topographic surface. Flattening water surfaces is the primary target of current (2017) treatments, but consumer demand for hydrologically enforced DEMs is driving development of additional types of DEM surface treatments.

Hydro-Flattening

Hydro-flattening pertains only to the creation of derived DEMs from lidar points and breaklines. Hydro-flattening makes no changes to the geometry of the originally computed lidar points. Breaklines developed for use in hydro-flattening may also be used to support classification of the point data.

Just as in stereo compilation, bare-earth lidar points (serving as mass points) that are in close proximity to any breakline shall be classified as Ignored Ground (class 20) and shall be excluded from the DEM generation process when the breaklines are included. This process prevents unnatural surface artifacts from being created between lidar points and breakline vertices. The proximity threshold for reclassification as Ignored Ground is at the discretion of the data producer, but in general should not exceed twice the ANPS.

The goal of the NGP is not to provide accurately mapped, geographically corrected water surface elevations within the standard national DEM available through The National Map—the goal is to produce topographic DEMs that, with respect to water surfaces, resemble DEMs derived from traditional photogrammetric methods and, to the degree practical, are free of unnatural triangulation effects. Best professional judgment is to be used to achieve this traditional smooth water surface effect. *See* appendix 2 for additional information on hydro-flattening.

The requirements for hydro-flattening are listed below. These requirements also define the minimum features for which breaklines shall be collected and delivered.

1. Inland Ponds and Lakes
   - Waterbodies with a surface area of 0.8 hectare (ha; 2 acres) or greater (approximately equal to a round pond 100 m in diameter) at the time of collection shall be flattened.
   - Flattened waterbodies shall present a flat and level water surface (a single elevation for every bank vertex defining the waterbody's perimeter).
   - The entire water surface edge shall be at or below the immediately surrounding terrain (the presence of floating waterbodies will be cause for rejection of the deliverable).
   - Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations decrease with downstream travel, shall be treated as streams or rivers.
2. Inland Streams and Rivers
   - Streams and rivers of a 30-m or greater nominal width shall be flattened.
   - Streams or rivers whose width varies above and below 30 m will not be broken into multiple segments; data producers will use their best professional cartographic judgment in determining when a stream or river has attained a nominal 30-m width.
   - Flattened streams and rivers shall present a flat and level water surface bank-to-bank (perpendicular to the apparent flow centerline).
   - Flattened streams and rivers shall present a gradient downhill water surface, following 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, the water surface will be represented as it exists while maintaining an aesthetic cartographic appearance.
   - The entire water surface edge shall be at or below the immediately surrounding terrain.
   - Stream channels shall break at culvert locations leaving the roadway over the culvert intact.
   - Streams shall be continuous at bridge locations.
   - Bridges in all their forms shall be removed from the DEM.
   - When the identification of a structure as a bridge or culvert cannot be made definitively, the feature shall be regarded as a culvert.
3. Non-Tidal Boundary Waterbodies
   - Boundary waterbodies are waterbodies that contain some or all of the DPA.
   - Boundary waterbodies may be any type of waterbody but are virtually always large in area or width.
   - A boundary waterbody shall be represented as a polygon that follows the shore throughout the project and is then closed using arbitrary line segments as needed across the waterbody. Boundary waterbodies do not include the natural far shoreline.
   - The water surface shall be flat and level, as appropriate for the type of waterbody (level for lakes, gradient for rivers, and so forth). It is not expected that ponds <0.8 ha (2 acres) or streams <30 m in width would be used as boundary waterbodies, thus it is expected that all boundary waterbodies will be hydro-flattened.

- All landward water surface edges shall be at or below the immediately surrounding terrain.
- Unusual changes in the water surface elevation that may take place over the course of the collection (for example, different river stages due to increased or decreased discharge from an upstream dam) shall be documented in the project metadata.
- Unusual changes in water surface elevation shall be handled as described in "4. Tidal Waterbodies" (below).

4. Tidal Waterbodies

Tidal waterbodies are defined as any waterbody that is affected by tidal variations, including oceans, seas, gulfs, bays, inlets, salt marshes, and large lakes. Tidal variations during data collection or between different data collections will result in lateral and vertical discontinuities along shorelines. Because it is the USGS–NGP's intent for the DEM to represent as much ground as the collected data permit, lidar ground points are not to be removed for the sake of adjusting a shoreline inland to match another shoreline. Likewise, adjusting a shoreline outland will create an equally unacceptable area of unmeasured land in the DEM. It is recommended that, to the highest degree practical, collections are planned to minimize tidal differences at the land-water interface. In addition to meeting the requirements for inland waterbodies listed in "1. Inland Ponds and Lakes" and "2. Inland Streams and Rivers" (above) as appropriate, the treatment of tidal waterbodies shall also meet the following requirements:

- Within each waterbody, the water surface shall be flat and level for each different water surface elevation.
- Vertical discontinuities within a waterbody resulting from tidal variations during the collection are considered normal and shall be retained in the final DEM.
- Horizontal discontinuities along the shoreline of a waterbody resulting from tidal variations during the collection are considered normal and shall be retained in the final DEM.

Long tidal waterbodies that also exhibit downhill flow (such as a fjord) can present unusual challenges; data producers are to exercise their best professional judgment in determining the appropriate approach solution to meet the overall goal of hydro-flattening as described in this section. For projects located in coastal areas, cooperating partners may impose additional requirements for tidal coordination.

5. Islands

- Permanent islands 0.4 ha (1 acre) (approximately equal to a round island 72 m in diameter) or larger shall be delineated within all waterbodies.

EleHydro Breakline GIS Data Dictionary

At this revision of the USGS–NGP Lidar Base Specification (version 1.3), the material in this section is provided solely as a recommended set of guidelines for use when developing hydrologic breaklines for 3DEP lidar projects. There is no requirement to collect any features described herein, other than those required for DEM hydro-flattening and bridge/saddle treatments, nor is there a current requirement to use the structure and format defined by this data dictionary. Data producers should be aware that use of the data dictionary and detailed feature capture requirements for EleHydro breaklines are anticipated in version 2.0 of the Lidar Base Specification.

In an effort to improve integration between elevation and hydrographic data, the NGP has developed a GIS data dictionary to provide a consistent data structure for breaklines. The data dictionary includes table structures, attribute field definitions, and defined domains for attribute values. This standardization will allow currently collected breaklines to be used consistently, not only for hydro-flattening but also to update and enhance National Hydrography Dataset (NHD) data.

In anticipation of expanded use of integrated EleHydro data, the data dictionary includes features that would typically be used by both elevation and hydrographic user communities. Many of these features are beyond the minimum features required for hydro-flattening. Specifications for these additional features extend the consistency of collected data for projects that require collection of optional features and may allow development of additional elevation products.

The structure of the attribute tables, field domains, and feature description to code relationships to use for EleHydro breaklines are shown in tables 7–11 (at the back of the report). Consistent use of this GIS data dictionary structure on all projects will allow the USGS to consolidate breaklines from multiple collections and exploit the data without project-by-project limitations.

In addition to the benefits of a standard data structure for breaklines, a fundamental benefit of this GIS data dictionary is to allow a single set of hydrologic breaklines to be used for dual purposes:

- *As 3D breaklines.*—These data are currently used to enhance the topographic DEM products by hydro-flattening waterbodies. Increased detail and an expanded set of captured features will allow the generation of improved topographic surfaces and generation of new hydrologic DEM surfaces for use in hydrologic and hydraulic (H&H) modeling applications.
- *As National Hydrography Dataset (NHD) vector features.*—Most of the breaklines identified in this GIS data dictionary correspond to hydrographic features of the NHD. Thus, once collected for use with 3DEP elevation products, and with proper attribution, they can also be used directly by the NHD with minimum

manipulation, improving the NHD's accuracy, detail, and currency.

The use of a single set of hydrologic breaklines for these dual purposes is fundamental to the reintegration of the NHD hydrography with 3DEP elevations. Operating under separate management for years, production of these two primary data layers for The National Map has diverged as lidar technology has increased the accuracy, resolution, and currency of elevation data much faster than updates could be made to hydrography. The USGS has sought methods to spatially reconcile these two intrinsically connected data layers (as well as the Watershed Boundary Dataset) for several years; this proposed approach is a major step forward to achieve that goal.

Breaklines are 3D lines or polygons (also referred to as "polylineZ" and "polygonZ" in many software applications) that define breaks in the elevation or slope of the landscape. Each vertex in a polylineZ or polygonZ has *x*, *y*, and *z* coordinate values. The *z* values of the vertices of a given line may or may not be the same as the other vertices in that feature. For example, in a single-line stream, the values will be different from one another, but in the bankline of a closed pond they will all be identical. Although it is possible to represent banklines of closed ponds as 2.5-dimensional (2.5D) lines/polygons (2-dimensional [2D] geometry with a single *z* value elevation attribute; often used for isolines), this specification defines all breakline features with full 3D geometry (all vertices have an assigned elevation value, whether identical or not).

The user of the EleHydro Breakline GIS data dictionary may find an example helpful for understanding the practical use in elevation applications of a breakline feature set, as described herein, combined with classified lidar data. A typical topographic DEM (for instance, current 3DEP topographic elevation products or the former NED) is principally used to generate topographic contours, which have appeared on USGS Topo Maps for decades. The topographic DEMs that are used to generate contours for the USGS Topo Maps and the U.S. Topo map products represent the *land surface* as it would appear from an aerial perspective. Man-made artificial surfaces above the land surface are not included—most notably bridge decks (regardless of what type of feature they traverse)—because they are not the *land* surface. A second type of topographic DEM, primarily used by the transportation data community, would instead leave the bridge decks in place and thus represent the complete surface and structure of transportation features.

A third type of DEM, the hydrologic DEM, is not used for traditional mapping and contouring; this type of DEM is intended for hydrologic and some types of hydraulic modeling. Hydrologic DEMs represent the flow of water across the surface, as it behaves in the physical world. Because elevation surfaces can represent only one elevation at a given *x,y* location, bridges and road fills over culverts will raise the DEM surface above the water flow and act as "digital dams" preventing correct water flow modeling. Thus, in hydrologic DEMs, bridge decks are removed and the land surface over culverts is removed.

It is critical to note that none of these DEM surfaces are better than, or improvements to, any other. They are simply different surfaces for different purposes.

Any or all of the above surface types can be created from a single, well-classified lidar dataset, and a properly and predictably formatted breakline dataset, by including or excluding selected lidar points and breaklines based on the type of surface desired. A standard topographic DEM is made using all bare-earth lidar points and the polygon breaklines that bound waterbodies (both lakes and rivers, for hydro-flattening). Single-line streams (not including culvert segments) can be added to the breaklines to enhance the ground surface by forcing linear depressions ("creases") into the surface to distinctly define drainages. A transportation DEM would add the bridge deck polygons and the bridge deck lidar points. A hydro-enforced DEM would remove the bridge deck polygons and points; further, it would include culvert breaklines (at the elevation of the drainage) and remove bare-earth points within a buffer of those breaklines. A visual depiction of how this is accomplished is shown in figures 6–12 (at the back of the report).

The preceding examples demonstrate how a properly structured and attributed set of breaklines can be used selectively with lidar points to create functionally different DEM surfaces, each appropriate for specific user applications. Three types of DEMS have been described, including topographic for contour generation, topographic for transportation use, and hydrologic for H&H use, but several other types can be produced easily, as well. Excerpts from the attribute tables of the polylineZ and polygonZ feature classes used in the examples above are shown in figures 13–16 (at the back of the report). For each feature class, two tables are shown: the first displays the actual numeric domain codes (what is actually in the table), and second table shows the corresponding domain code descriptions (the domain codes, translated to text by ArcGIS). A complete listing of the domain codes is provided in table 8 and descriptions of the feature types are available in tables 9–11 and the associated text.

The value of using properly and consistently collected hydrologic breaklines does not end with expanded and improved elevation surfaces. Those who work in the water sciences will immediately recognize the close similarity between the types of lines collected for DEM construction and those of the NHD. The two sets of linework are overlaid for comparison in figure 17 (at the back of the report).

Several important differences should be noted between the NHD and lidar breaklines:

- The lidar breaklines are more spatially accurate.
- The lidar breaklines have a greater spatial resolution and thus, are more detailed.
- The lidar breaklines are in most cases more temporally current.

- The lidar breaklines are more functionally descriptive (for example, culverts are differentiable from streams).

Although the NHD's primary purpose is as a hydrologic data model, which it fulfills quite well, it is often used for other, less suitable purposes. Cartographically, it often does not match orthophotography and other features collected more recently, though it remains in use within The National Map. The 3D integration of the NHD and the existing 3DEP standard elevation products is particularly problematic because drainages exist in the landscape where the topography dictates—this is often not where the NHD linework indicates. One solution to the integration problem that has been in use for years is the "wall and burn" technique, where the topographic DEM is modified to conform to the less accurate, less detailed, and less current NHD.

Updating the NHD to conform to the elevation surfaces on which it is based in the physical world is a substantial undertaking; however, there is now an exceptional opportunity to begin a new approach to EleHydro integration. When hydrologic breaklines are created using standard rules for topology and attribution, the resulting set of highly accurate breaklines can be used not only for generation of multiple types of DEMs, but also directly to update and refine the 3D geometry of the NHD. The EleHydro GIS data dictionary defined below is a draft proposal of the attribute structure needed to satisfy the requirements for DEM production of the elevation and the hydrography communities.

Most feature topology is identical across elevation and hydrography—the two most important differences are the following:

1. In the NHD, a stream passing through a culvert under a road fill is not broken out as a separate line; it remains coded as a stream. For elevation purposes, the culvert portion must be differentiated from the stream. Thus, for collection, a culvert must be a separate feature, node-matched (snapped) at each end to the up and downstream stream features. Elevation attribution will identify the culvert separately; NHD attribution will be the same for both the streams and the culvert, allowing the NHD to merge the features and thereafter use them in the traditional NHD manner.

2. In the NHD, linear and polygonal features are continuous where they pass beneath bridges, as the NHD disregards bridge structures, as does the 3DEP in a *traditional topographic DEM*; however, other types of DEMs, such as those used for transportation, require bridge decks to remain in the surface model, necessitating the removal of the hydrologic features beneath the bridge. For collection, these hydrologic features will be collected intact; 3DEP can cookie-cut these pieces using the bridge polygon breaklines, and add the "obscured" attribute flag in the process.

The following topology rules shall be enforced for all linear breakline features that represent the flow of water:

- Lines shall be oriented from upstream to downstream.
- Each vertex in a line shall be at the same or a lower elevation value than the preceding vertex.
- All lines shall be at or just below the elevation of the immediately surrounding terrain, as defined by the lidar points classified as bare-earth.
- All lines shall begin or end at the intersections, without pseudo-nodes or breaks within reaches.
- Polygonal water features shall begin and end at the upstream end of that polygon's centerline (artificial path).
- Where any other features intersect, the intersection shall be coincident with vertices of each feature.
- At all intersections, regardless of feature type, the geometry of all intersection vertices shall match exactly in *x, y,* and *z*.

It is important to note that all features collected shall be logically and spatially consistent with the lidar data, both horizontally and vertically. Breaklines are intended first for integration with the lidar data. This requirement holds true regardless of "scale" or level of detail collection requirements. Put another way, if the collection is specified for NHD features at the 1:24,000 NHD specification, the set of features collected must satisfy the requirements for 1:24,000 NHD, but the geometry and spatial accuracy of those features must still conform to the lidar data.

Breaklines are intended to add important elevation information to the surface. Some breakline collection methods inherently produce 3D lines with discrete elevation information, and there are numerous methods implemented in commercial software to make 2D breaklines into 3D breaklines. Merely draping a line onto a surface made solely from the lidar points does not achieve the intended goal and is not acceptable.

Attribute Table Structure

The structure of the attribute tables is described in table 7. First, note that all three breakline feature classes (pointZ, polylineZ, and polygonZ) are 3D geometry and that there is no attribute for elevation (as in a 2.5D model). Second, the table structures for all three feature classes are identical.

Ignoring the system generated fields (*FID* and *Shape*) in the attribute tables, the first two fields are *FGroup* and *FCode*, which are direct analogues to the NHD data dictionary (U.S. Geological Survey, 2010) and in virtually all cases are populated exactly as they would be in the NHD. The case of culverts, discussed above, is a notable exception.

The next two fields in the attribute tables are *EClass* and *EType*, which contain the codes used to identify the correct breaklines to use in various DEM production processes.

The *SFType* field is a direct equivalent to the Esri SFType: the numeric codes identify how each feature is to be used in constructing a TIN or Terrain surface.

Two floating point fields, *Exclude1* and *Exclude2* are provided to contain user-defined buffer distances. These buffers are used in surface generation to exclude lidar ground points around individual breakline features in the output DEM. For example, consider a lidar collection with a NPS of 0.5 m. All single-line streams might be given an *Exclude1* value of 1.5, meaning that ground points within 1.5 m to either side of the line would be excluded from the TIN and resulting DEM. This buffer of excluded points ensures that drainage is cleanly defined in the final surface product without introducing unwanted TIN artifacts. A large culvert segment, on the other hand, might be assigned a value of 5, which will remove all lidar points in a 10-m-wide path centered on the culvert line. This wider channel ensures that the flow path on the surface is open and clear and permits more realistic modeling of surface-water flow across the DEM surface. These fields allow the user to store two different values for each feature, which is a convenience where breaklines are used for different types of functional surfaces or DEM resolutions. The Exclude values are usually defined and set by the end user.

The *Obscurity* field is a binary (0/1; True/False) field used to indicate whether or not a given hydrologic feature is obscured by a bridge deck (EType 1301). It is not used to identify features obscured by vegetation or other structures.

The *Description* field is a 128-character free-text field for user comments and notes.

The allowable codes and short descriptions for each of the attribute fields are listed in table 8. It is important to recognize that this list does not include all of the NHD codes and features; it only includes the features and codes potentially needed by both 3DEP and their NHD counterparts. The full NHD data dictionary (U.S. Geological Survey, 2010) is to be used if additional information is needed.

NHD FCodes are hierarchical: major digits (left side of the FCode) are high-level feature types; minor digits (right side of the FCode) identify subtypes of the broader “parent” type (for example, “stream/river - general” has an FCode of 46000, whereas a “stream/river—intermittent” has an FCode of 46003). Only the higher level FCodes in the form ###00 are used for EleHydro breaklines. Many of the more detailed subtypes cannot be reliably determined from lidar and imagery alone, often requiring intimate local knowledge or possibly even field verification. This approach allows higher confidence in the more general information rather than lower confidence in specific details. Cross-walks between 3DEP elevation and NHD coding for all of the relevant features as of the LBS version 1.3 are shown in tables 9–11.

The few point features that might be collected to support lidar-derived elevation surface generation are shown in table 9. Gates, Dams, and Weirs, although not uncommon features, are infrequently needed in the development of surface elevation models but can add worthwhile information in some circumstances. Spot elevations are known, surveyed points of high accuracy that are typically three times greater than the lidar data itself. When available, these elevation points are valuable for elevation applications but are not part of the NHD and therefore are assigned undefined NHD values for FGroup and FCode (0, 00000).

Linear breakline features are described in table 10. Several feature distinctions should be noted:

- *Stream*: This refers to a simple, single-stream channel with a width narrower than the requirement for collection as a polygon. The width requirement for polygonal collection is 30 m (approximately 100 feet); *however,* that threshold is not absolute and may be contractually different on any individual project.

- *Canal/Ditch:* This feature designation is similar to a stream but is reserved for features that are clearly man-made and are usually much straighter than naturally flowing open channel streams.

- *Culvert:* Culverts are subsurface water conveyances topped with earth (as opposed to an elevated bridge deck over an open waterway). S*ee* the “Glossary” section. Culverts may be small corrugated metal pipes running under a driveway or massive concrete box culverts under superhighways. Most culvert features will be simple lines connecting the upstream and downstream segments of single-line streams. In the case of a large culvert connecting two polygonal waterbodies (that is, a river), a polygonal culvert should be collected, with an additional culvert centerline to connect the interrupted river centerline segments.

- *Pipeline:* Includes siphons, penstocks, and aqueducts. These features are needed to establish connectivity between two otherwise separate water features. Pipelines are often buried or pass through dams; however, their existence is functionally apparent.

- *Spillway:* An overflow channel connecting an impoundment behind a dam to the watercourse downstream from the dam. Most dams also have a weir or other structure to allow water to pass from the impoundment through the dam. Whether the spillway or weir, or both, are to be collected is at the discretion of the customer.

- *Stream Braid:* In areas where a stream is braided into a complex channel, the apparent Main Channel (most dominant water flow) will be identified as a *Stream*. The other channel braids will be identified as *Stream Braids.* This statement refers only to linear streams. Braided *rivers* (wide and represented as polygons) are handled differently.

- *Centerline:* These are artificial paths that approximate the center flow within a waterbody, including both flowing and nonflowing waterbodies. These paths serve two critical functions: (1) providing continuous network connectivity for H&H modeling; and (2) providing a mechanism to correctly assign elevations to the breaklines delineating the banks of the river or lake.

- *Link:* A link is a short connecting line that connects a single-line stream to the centerline of a polygonal waterbody.
- *Elevation Terminus:* This is a virtual feature that does not represent any real-world phenomena. It provides a common element to which numerous other hydrologic features can connect at their termination, and most importantly, impose a single elevation for their termination points. A single termination elevation is often necessary in coastal situations where multiple rivers flow into the ocean and thus, ostensibly, end at the same elevation. Changing tide levels during a collection usually makes it impossible to achieve agreement in elevations at the mouths of multiple rivers; these variations can have undesired effects on how elevation conflation is performed upstream. There is no corresponding NHD feature for this element.
- *Flattener:* These are also virtual features that support proper conflation of elevation values to shoreline vertices, but do not represent any actual real-world feature. In waterbodies (rivers, reservoirs) with complex shorelines, flatteners extend from the upper ends of peripheral arms down to the centerline. There is no corresponding NHD feature for this element, which is depicted in figure 18 (at the back of the report).

Polygonal breakline features are described in table 11. Several feature distinctions should be noted:

- All polygonal water features, except playas and headwater ponds, shall contain a centerline appropriate to the type of polygon to maintain a complete linear streamflow network.
- *Lake/Pond:* This is limited to waterbodies that have a constant Water Surface Elevation (WSEL) on their perimeter. Waterbodies that have uphill to downhill flow (fjords, reservoirs, and so forth) are not to be coded as *Lake/Pond.*
- *Playa:* Where identifiable, both wet and dry playas are identified using the indicated FCodes for NHD use. Dry playas are assigned the EType code 1116; wet playas are assigned the EType code 1106 (same as *Lake/Pond*).
- *Large Channelized River:* This is a seldom used special use case. Due to the diverse nature of these features, the specific application will be determined on a case-by-case basis in consultation with the customer, 3DEP staff, and NHD staff. In any case, these polygonal features shall also contain a centerline to maintain the linear stream flow network. One example of a large channelized river (the Los Angeles River) is shown in figure 19 (at the back of the report).
- *Reservoir:* An impoundment large enough that its WSELs vary from upstream to downstream, as with a River.
- *Fjord:* For our purposes, a large waterbody that behaves much like a river or reservoir in that its WSEL changes from high to low as it flows to the sea, but it is open to the sea, not dammed. These features are handled slightly differently in the elevation conflation process and need to be differentiable from other waterbodies. Fortunately, there are only two in the CONUS.
- *Boundary Waterbody:* Any waterbody that contains the boundary of the collection (that is, the actual opposite bank or shore is not being mapped). Boundary waterbodies may be a single WSEL (for example, lake) or gradient (for example, river). Boundary waterbodies will contain either a centerline or an Elevation Terminus line, depending on circumstances.
- *Bridge Deck:* The outline of the elevated bridge deck or surface (any type; *see* "Glossary" section). This will include elevated ramps and travel ways. Features will be delineated using the fewest vertices possible (often only four) to maintain the most regular shape that still conforms to the lidar points.
- *Culvert:* This is for large box culverts that connect polygonal water features. The culvert polygon shall include a centerline (also EType 1103) that connects the centerlines of the adjoining waterbodies.
- *Swamp/Marsh:* A reference polygon used by 3DEP to define an area of normally wet, soggy, or shallow water conditions. Strict definitions (for swamp, marsh, wetland, and so on), usually from other agencies or organizations, do not necessarily apply. Depending on circumstances and location, these hydrographic features may or may not be included in the hydrologic network, and therefore may or may not include a centerline.
- *Braided Stream Area:* A reference polygon used by 3DEP to define an area where a stream or river is braided. It may encompass either single-line streams or polygonal rivers. Note that this is **NOT** the same type of feature as the NHD "Area of Complex Channel" identified by FCode 53700, a feature that is **NOT** included in the EleHydro data dictionary. A graphic example of this feature type is shown in figure 20 (at the back of the report).
- *Unusually Inundated Area:* A reference polygon used by 3DEP to define an area that, although normally dry land, was flooded, slightly inundated, or rendered swampy at the time of lidar collection. These areas are

not part of the hydrologic network and thus will not include any centerline.

- *Island/Sandbar—Intermittently/Partially Submerged:* Polygons representing identifiable islands or parts of islands that are submerged at the time of collection. These are most often found in coastal areas due to tidal variations during the collection, or in rivers collected while at a high flow.

- *Low Confidence Area (pre-determined):* A reference polygon used by 3DEP to define an area where lidar penetration to the bare-earth surface is expected to be substandard. These areas would be established prior to the collection and agreed upon by the data producer and the customer. Examples might include known areas of mangroves or triple-canopy tropical rainforest.

- *Low Confidence Area (sparse bare earth):* A reference polygon used by 3DEP to define areas where lidar penetration to the bare-earth surface was determined to be substandard during production. The criteria for "low confidence" shall be established prior to the collection and agreed upon by the data producer and the customer.

- *Low Confidence Area (snow-covered):* A reference polygon used by 3DEP to define where it can be determined that there was snow on the ground at the time of collection. Light dustings of snow that do not alter the ground elevation more than about 2 cm are inconsequential and should not be delineated.

Optional Additional Breaklines

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

- The final DEM shall be a hydro-flattened (not hydro-enforced) topographic DEM suitable for integration into the standard national DEM available through The National Map (refer to appendix 2 for more information on hydro-enforcement).

- All vertices along single-line stream breaklines shall be at or below the immediately surrounding terrain.

- Breaklines representing single-line streams, culverts, or other hydrographic features shall not be used to introduce hydrologic flow paths through road crossings (culverts), dams, or other similar topographic features in hydro-flattened DEMs, but shall be suitable for such use in the creation of hydro-enforced DEMs.

- All additional breaklines developed for the project shall be delivered to the USGS.

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Tables

Table 1. Aggregate nominal pulse spacing and density.

[QL, quality level; pls/m^2, pulses per square meter; m, meter; ≤, less than or equal to; ≥, greater than or equal to]

Quality level	Aggregate nominal pulse spacing (m)	Aggregate nominal pulse density (pls/m^2)
QL0	≤0.35	≥8.0
QL1	≤0.35	≥8.0
QL2	≤0.71	≥2.0
QL3	≤1.41	≥0.5

Table 2. Relative vertical accuracy for light detection and ranging swath data.

[QL, quality level; $RMSD_z$, root mean square difference in the *z* direction; m, meter; ≤, less than or equal to]

Quality level	Smooth surface repeatability, $RMSD_z$ (m)	Swath overlap difference, $RMSD_z$ (m)
QL0	≤0.03	≤0.04
QL1	≤0.06	≤0.08
QL2	≤0.06	≤0.08
QL3	≤0.12	≤0.16

Table 3. Land cover classes.

[FVA, fundamental vertical accuracy; SVA, supplemental vertical accuracy; NVA, nonvegetated vertical accuracy; VVA, vegetated vertical accuracy; n/a, not applicable or not available]

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

Table 4. Absolute vertical accuracy for light detection and ranging data and digital elevation models.

[QL, quality level, $RMSE_z$, root mean square error in the *z* direction; NVA, nonvegetated vertical accuracy; VVA, vegetated vertical accuracy; m, meter; ≤, less than or equal to]

Quality level	$RMSE_z$ (nonvegetated) (m)	NVA at the 95-percent confidence level (m)	VVA at the 95th percentile (m)
QL0	≤0.050	≤0.098	≤0.15
QL1	≤0.100	≤0.196	≤0.30
QL2	≤0.100	≤0.196	≤0.30
QL3	≤0.200	≤0.392	≤0.60

Table 5. Minimum light detection and ranging data classification scheme.

Code	Description
1	Processed, but unclassified
2	Bare earth
7	Low noise
9	Water
17	Bridge deck
18	High noise
20	Ignored ground (*typically breakline proximity*)
21	Snow (*if present and identifiable*)
22	Temporal exclusion (*typically nonfavored data in intertidal zones*)

Table 6. Minimum digital elevation model cell size.

[QL, quality level; m, meter; ft, feet]

Quality level	Minimum cell size (m)	Minimum cell size (ft)
QL0	0.5	1
QL1	0.5	1
QL2	1	2
QL3	2	5

Table 7. Attribute table structure for EleHydro breakline features.

[ID, identifier; FID, feature identifier; NHD, National Hydrography Dataset; n/a, not applicable or not available. EClass, EType, SFType, FGroup, and FCode are user field names that represent Elevation Class, Elevation Type, Surface Feature Type, Feature Group, and Feature Code, respectively.]

Attribute	Item name	Item type	Item precision	Item scale
Point features				
Feature ID	*FID*	*Object ID*	*system*	
Shape	*Shape*	*Geometry, PointZ*	*system*	
Feature Group (NHD)	FGroup	Short	4	0
Feature Code (NHD)	FCode	Long	5	0
Feature Class (Elevation)	EClass	Short	4	0
Feature Type (Elevation)	EType	Short	4	0
Surface Feature Type	SFType	Short	4	0
Exclude Distance 1	Exclude1	Float	8	2
Exclude Distance 2	Exclude2	Float	8	2
Description	Desc	Text	128	n/a
Obscurity	Obscurity	Short	2	0
Line features				
Attribute	**Item name**	**Item type**	**Item precision**	**Item scale**
Feature ID	*FID*	*Object ID*	*system*	
Shape	Shape	*Geometry, PolylineZ*	*system*	
Feature Group (NHD)	FGroup	Short	4	0
Feature Code (NHD)	FCode	Long	5	0
Feature Class (Elevation)	EClass	Short	4	0
Feature Type (Elevation)	EType	Short	4	0
Surface Feature Type	SFType	Short	4	0
Exclude Distance 1	Exclude1	Float	8	2
Exclude Distance 2	Exclude2	Float	8	2
Description	Desc	Text	128	n/a
Obscurity	Obscurity	Short	2	0
Polygon features				
Attribute	**Item name**	**Item type**	**Item precision**	**Item scale**
Feature ID	*FID*	*Object ID*	*system*	
Shape	*Shape*	*Geometry, PolygonZ*	*system*	
Feature Group (NHD)	FGroup	Short	4	0
Feature Code (NHD)	FCode	Long	5	0
Feature Class (Elevation)	EClass	Short	4	0
Feature Type (Elevation)	EType	Short	4	0
Surface Feature Type	SFType	Short	4	0
Exclude Distance 1	Exclude1	Float	8	2
Exclude Distance 2	Exclude2	Float	8	2
Description	Desc	Text	128	n/a
Obscurity	Obscurity	Short	2	0

Table 8. Domain values and descriptions for feature attributes.

[NHD, National Hydrography Dataset. EClass, EType, SFType, FGroup, and FCode are user field names, specified in table 7. They represent Elevation Class, Elevation Type, Surface Feature Type, Feature Group, and Feature Code, respectively.]

NHD related codes				Elevation related codes				General codes			
FGroup		FCode		EClass		EType		SFType		Obscurity[1]	
0	Non-NHD	00000	Non-NHD	0	Non-Elevation	0000	Non-Elevation	0	Ignore	0	<blank>
1	NHD Point	31200	Bay/Inlet	1	Hydrologic	1001	Spot Elevation	1	Mass point	1	Obscured
2	NHD Line	33400	Connector	2	Topographic	1003	Gate	2	Soft Line		
3	NHD Flowline	33600	Canal/Ditch	3	Manmade	1004	Dam/Weir	3	Hard Line		
4	NHD Area	34300	Dam/Weir	9	Reference	1101	Stream	4	Soft Replace		
5	NHD Water-body	36100	Playa			1102	Canal/Ditch	5	Hard Replace		
		36900	Gate			1103	Culvert	6	Soft Clip		
		39000	Lake/Pond			1104	Spillway	7	Hard Clip		
		42813	Pipeline–Siphon			1105	Stream Braid	8	Soft Erase		
		42815	Pipeline–Penstock			1106	Lake/Pond	9	Hard Erase		
		42816	Pipeline–Aqueduct			1116	Playa	10	Soft Fill		
		43600	Reservoir			1107	River	11	Hard Fill		
		43612	Sewage Treatment–Settling Pond			1108	Reservoir	12	Barrier		
		44500	Sea/Ocean			1109	Fjord				
		45000	Sink/Rise			1110	Bay/Inlet/Sound				
		45500	Spillway			1111	Boundary Water-body				
		46000	Stream/River			1201	Centerline				
		46600	Swamp/Marsh			1202	Link				
		53700	Complex Channel			1203	Elevation Terminus				
		55800	Artificial Path			1204	Flattener				
		56600	Coastline			1205	Pipeline				
						1301	Bridge Deck				
						1303	Topographic Feature				
						1401	Swamp/Marsh Area				
						1402	Braided Stream Area				
						1403	Unusually Inun-dated Area				
						1404	Island/Sandbar—In-termittently/Par-tially Submerged				
						1501	Low Confidence Area (pre-determined)				
						1502	Low Confidence Area (sparse bare earth)				
						1503	Low Confidence Area (snow-covered)				

[1]In the EleHydro database, "obscurity" is used to identify feature segments that lie beneath bridge decks, not those obscured by vegetation or other structures. Usually these are sections of rivers, lakes, centerlines, single-line streams, or other features where they pass under bridges (EType 1301).

Table 9. Codes for EleHydro breakline point features.

[tbd, to be determined; NHD, National Hydrography Dataset; n/a, not applicable or not available. EClass, EType, SFType, FGroup, and FCode are user field names, specified in table 7. They represent Elevation Class, Elevation Type, Surface Feature Type, Feature Group, and Feature Code, respectively. Gray shading indicates codes that are not relevant for the data type in that column.]

Elevation description	EClass	EType	SFType	NHD description	FGroup	FCode
Features as points						
Spot elevation (verified as high accuracy)	2	1001	1	n/a	0	00000
Gate (connecting two single-line flows; marks a potential change in flow direction)	3	1003	tbd	Gate	1	36900
Dam/Weir (connecting two single-line flows; marks a change in water surface elevation)	3	1004	tbd	Dam/Weir	1	34300
Other topographic element	2	1303	tbd	n/a	0	00000

Table 10. Codes for EleHydro breakline line features.

[tbd, to be determined; NHD, National Hydrography Dataset; n/a, not applicable or not available. EClass, EType, SFType, FGroup, and FCode are user field names specified in table 7. They represent Elevation Class, Elevation Type, Surface Feature Type, Feature Group, and Feature Code, respectively. Gray shading indicates codes that are not relevant for the data type in that column.]

Elevation description	EClass	EType	SFType	NHD description	FGroup	FCode
Features as lines						
Gate (crossing polygonal water features; marks a potential change in flow direction)	3	1003	tbd	Gate	2	36900
Dam/Weir (crossing polygonal water features; marks a change in water surface elevation)	3	1004	tbd	Dam/Weir	2	34300
Stream (narrow; depicted as single line; in a braided area, the apparent main channel)	1	1101	tbd	Stream/River	3	46000
Canal/Ditch (narrow; depicted as single line)	1	1102	tbd	Canal/Ditch	3	33600
Culvert (single line, or centerline of polygonal culvert)	1	1103	tbd	→ if in Stream/River	3	46000
			tbd	→ if in Canal/Ditch	3	33600
			tbd	→ if in Artificial Path	3	55800
Spillway (single line, or centerline of polygonal spillway)	1	1104	tbd	→ if in Stream/River	3	46000
			tbd	→ if in Canal/Ditch	3	33600
			tbd	→ if in Artificial Path	3	55800
Stream braid (narrow single-line streams; not the apparent main channel)	1	1105	tbd	Stream/River	3	46000
Centerline (any waterbody)	1	1201	tbd	Artificial Path	3	55800
Link (single line to centerline)	1	1202	tbd	Artificial Path	3	55800
Pipeline (siphon, penstock, or aqueduct - possibly buried)	1	1205	tbd tbd	→ if Siphon	3	42813
				→ if Penstock	3	42815
				→ if Aqueduct	3	42816
n/a	0	0000	tbd	Connector (see NHD definition)	3	33400
n/a	0	0000	tbd	Coastline (see NHD definition)	3	56600
Elevation terminus line (that is, artificial centerline of a boundary waterbody)	1	1203	tbd	n/a	0	00000
Flattener	1	1204	tbd	n/a	0	00000
Other topographic element	2	1303	tbd	n/a	0	00000

Table 11. Codes for EleHydro breakline polygon features.

[tbd, to be determined; n/a, not applicable or not available; NHD, National Hydrography Dataset. EClass, EType, SFType, FGroup, and FCode are user field names, specified in table 7. They represent Elevation Class, Elevation Type, Surface Feature Type, Feature Group, and Feature Code, respectively. Gray shading indicates codes that are not relevant for the data type in that column.]

Elevation description	EClass	EType	SFType	NHD description	FGroup	FCode
Features as polygons						
Dam/Weir (large; also use Centerline [EType 1201] as centerline)	3	1004	tbd	Dam/Weir (large; also use Artificial Path as centerline)	4	34300
Canal/Ditch (wide, also use Centerline [EType 1201] as centerline)	1	1102	tbd	Canal/Ditch (wide; also use Artificial Path as centerline)	4	33600
Spillway (large; also use Spillway [EType 1104] as centerline)	1	1104	tbd	Spillway (large; also use Artificial Path as centerline)	4	45500
Lake/Pond (use Centerline [EType 1201] as centerline unless sewage treatment or settling pond)	1	1106	tbd	Lake/Pond (also use Artificial Path as centerline)	5	39000
				→ if sewage treatment or settling pond	5	43612
Playa (wet; use no centerline)	1	1106	tbd	Playa (wet)	5	36100
Playa (dry; use no centerline)	1	1116	tbd	Playa (dry)	5	36100
River (wide, also use Centerline [EType 1201] as centerline)	1	1107	tbd	Stream/River (wide; also use Artificial Path as centerline)	4	46000
If braided or with numerous islands, the centerline shall follow the apparent main channel.			tbd	Area of Complex Channel (wide, complex river; also use Artificial Path as centerline of the apparent main channel only)	4	53700
Large, channelized river (see note below)	1	1117	tbd	Stream/River (Wide; also use Artificial Path as centerline)	4	46000
Reservoir (use Centerline as centerline)	1	1108	tbd	Reservoir (also use Artificial Path as centerline)	5	43600
Fjord	1	1109	tbd	→ if Sea/Ocean	4	44500
			tbd	→ if Stream/River	4	46000
			tbd	→ if Lake/Pond	5	39000
Boundary Waterbody	1	1111	tbd	→ if Sea/Ocean	4	44500
			tbd	→ if Stream/River	4	46000
			tbd	→ if Lake/Pond	5	39000
Bridge Deck (Any type)	3	1301	tbd	→ if Water Conveyance Bridge; (extremely rare)	4	31800
				→ (else) n/a	0	00000
Swamp/Marsh Area (reference area for Elevation)	9	1401	tbd	Swamp/Marsh	5	46600
Braided Stream Area (reference area for Elevation) (not the same as the NHD FCode 53700)	9	1402	tbd	n/a	0	00000
Unusually Inundated Area (reference area for Elevation)	9	1403	tbd	n/a	0	00000
Island/Sandbar - Intermittently/ Partially submerged	2	1404	tbd	n/a	0	00000

Table 11. Codes for EleHydro breakline polygon features.—Continued

[tbd, to be determined; n/a, not applicable or not available; NHD, National Hydrography Dataset. EClass, EType, SFType, FGroup, and FCode are user field names, specified in table 7. They represent Elevation Class, Elevation Type, Surface Feature Type, Feature Group, and Feature Code, respectively. Gray shading indicates codes that are not relevant for the data type in that column.]

Elevation description	EClass	EType	SFType	NHD description	FGroup	FCode
Features as polygons (continued)						
Low Confidence Area (pre-determined) (reference area for Elevation)	9	1501	tbd	n/a	0	00000
Low Confidence Area (sparse bare earth) (reference area for Elevation)	9	1502	tbd	n/a	0	00000
Low Confidence Area (snow-cover) (reference area for Elevation)	9	1503	tbd	n/a	0	00000
Culvert (large) also use Culvert Line as centerline (uncommon)	1	1103	tbd	n/a	0	00000
Other topographic element	2	1303	tbd	n/a	0	00000

Figures

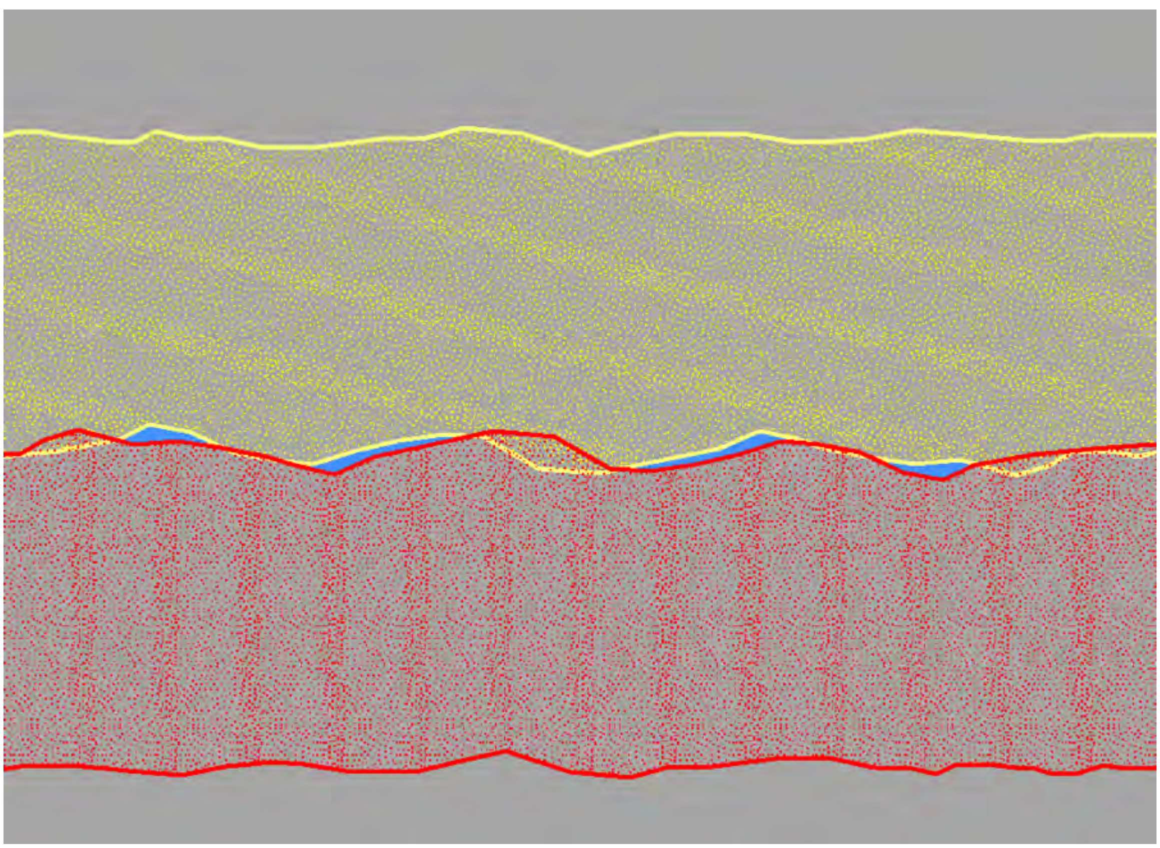


Figure 1. Single coverage collection, no overlap. Adjacent swaths (red and yellow) in this example have been collected with insufficient overlap, causing gaps in coverage. The blue areas depict data voids, which are grounds for rejection of the project.

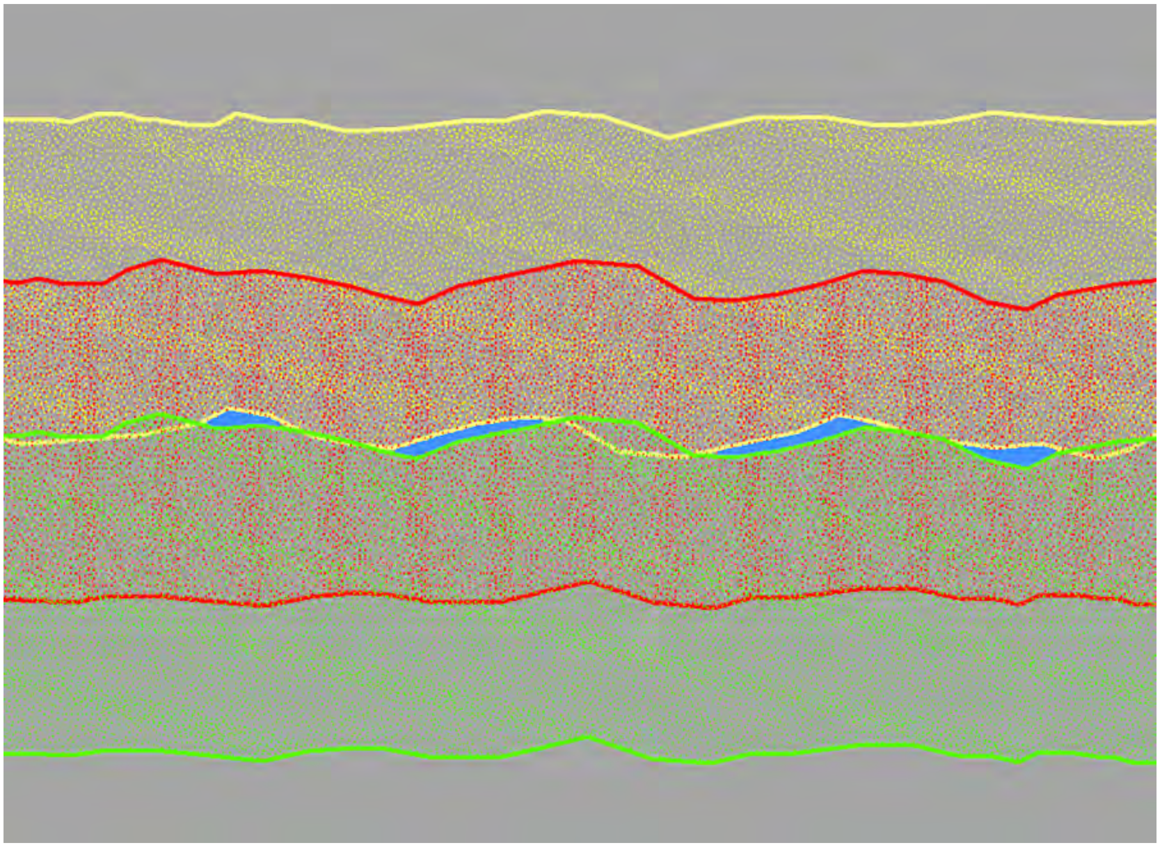


Figure 2. Designed double coverage collection, 50-percent overlap. In this example, three adjacent overlapping swaths (green, red, and yellow) have been collected. Because the design of the project achieved the required aggregate nominal pulse density (ANPD) through double-coverage, the blue areas that are not covered by two swaths are considered data voids, which are grounds for rejection of the project.

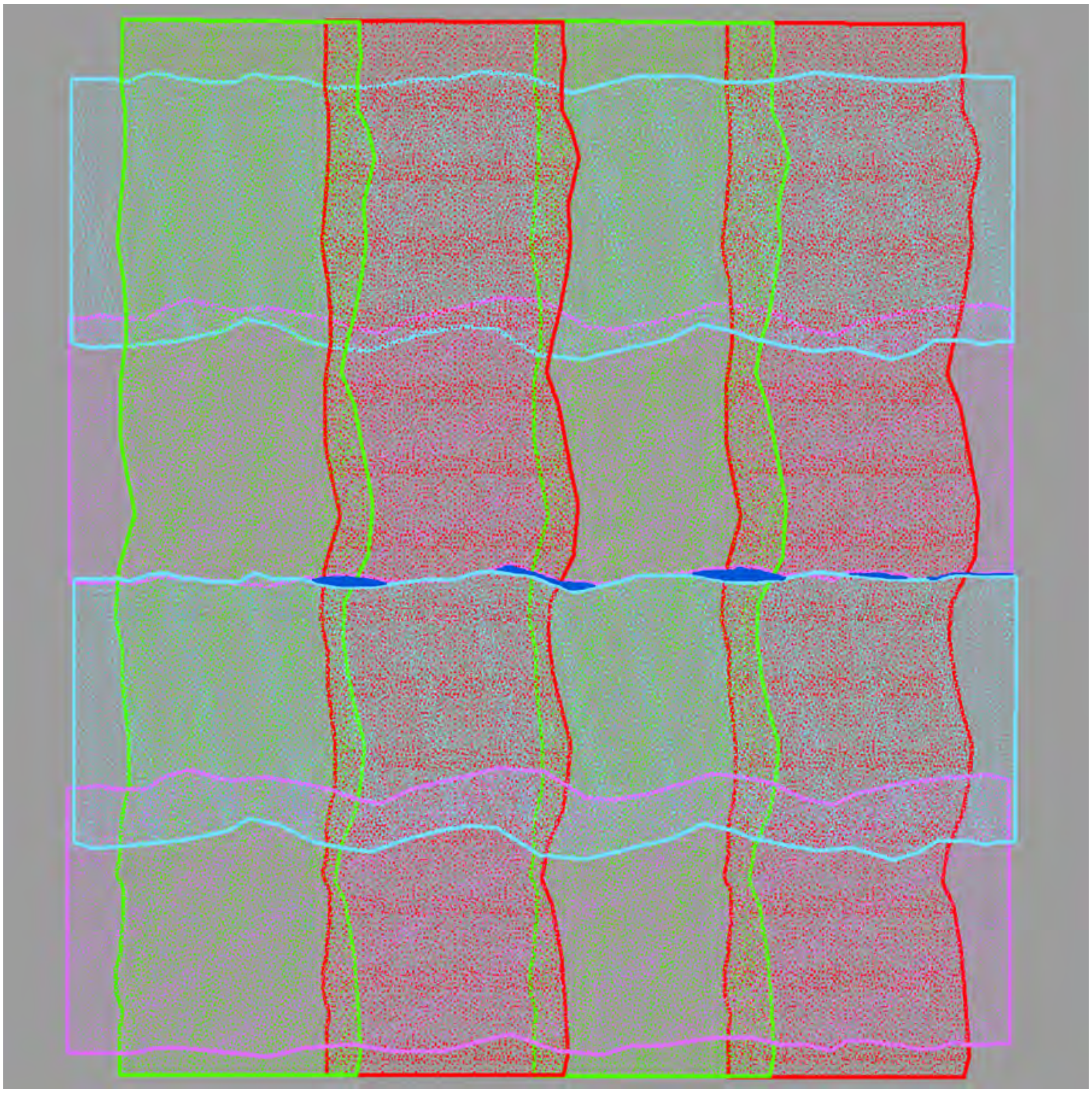


Figure 3. Designed double coverage collection, cross-flights with 20-percent overlap. Four overlapping swaths, shown in green, red, cyan, and magenta are shown in this example. The lower cyan swath was erroneously flown too far south, causing the data voids shown in blue. Because the design of the project was to achieve the required aggregate nominal pulse density through cross-flight double-coverage, the blue areas that are not covered by both a horizontal and a vertical swath are considered data voids, which are grounds for rejection of the project.

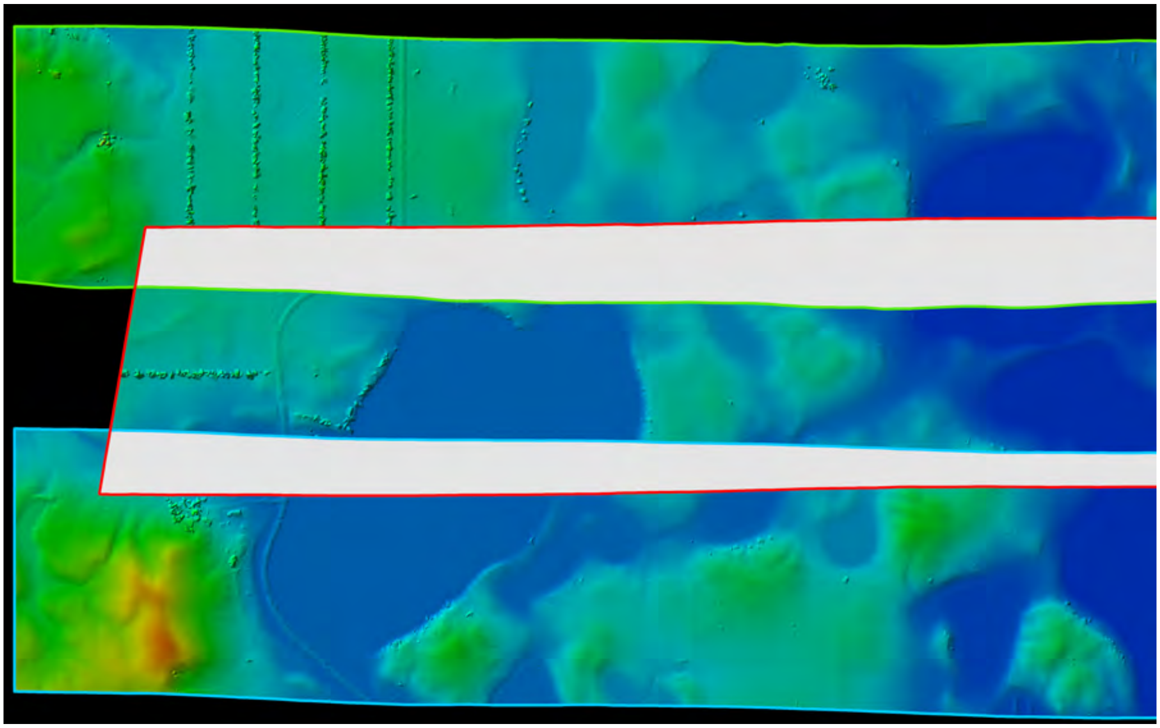


Figure 4. Graphic depiction of swath overlap. Three light detection and ranging swaths are depicted with the edges colored blue, red, and green. Each adjacent pair of swaths shares one overlap region shown in gray.

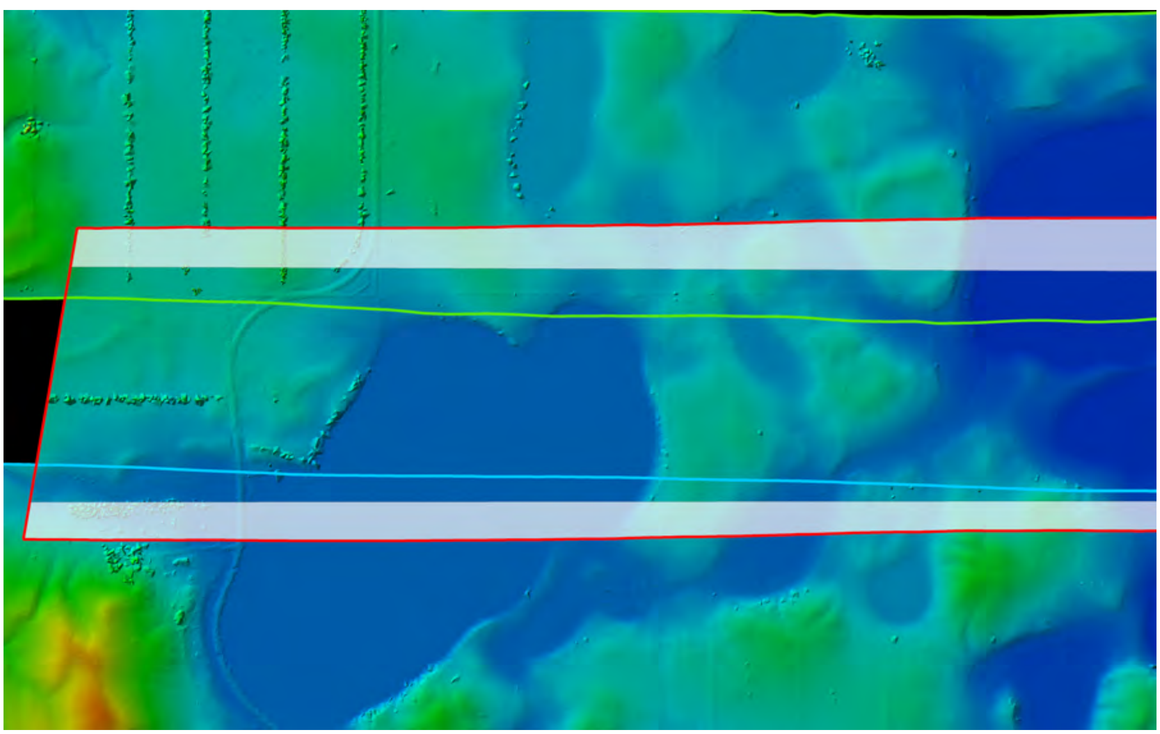


Figure 5. Graphic depiction of swath overage. Three light detection and ranging swaths are depicted with the edges colored blue, red, and green. Each individual swath has an overage region shown in gray for each adjacent, overlapping swath.

Figure 6. Sample EleHydro breakline area, Cabell County, West Virginia. Image courtesy of the West Virginia State Address and Mapping Board, 2004.

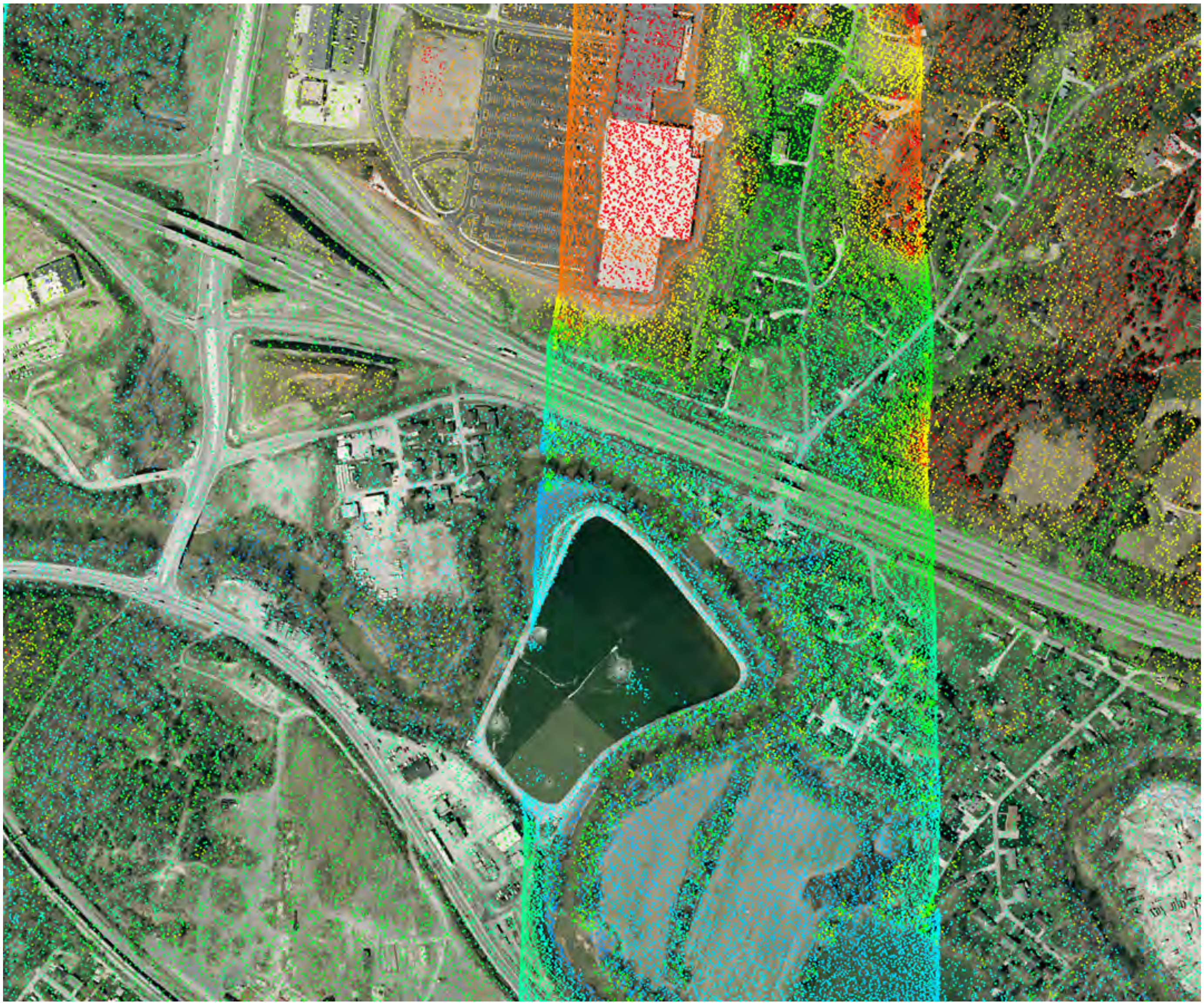


Figure 7. Sample area overlaid with light detection and ranging points. This demonstrates the point coverage colored by elevation from blue (low) to red (high). The point density has been dramatically reduced in this image to allow the base image to remain visible. Image courtesy of the West Virginia State Address and Mapping Board, 2004. Light detection and ranging data courtesy of Cabell County, West Virginia, 2009.

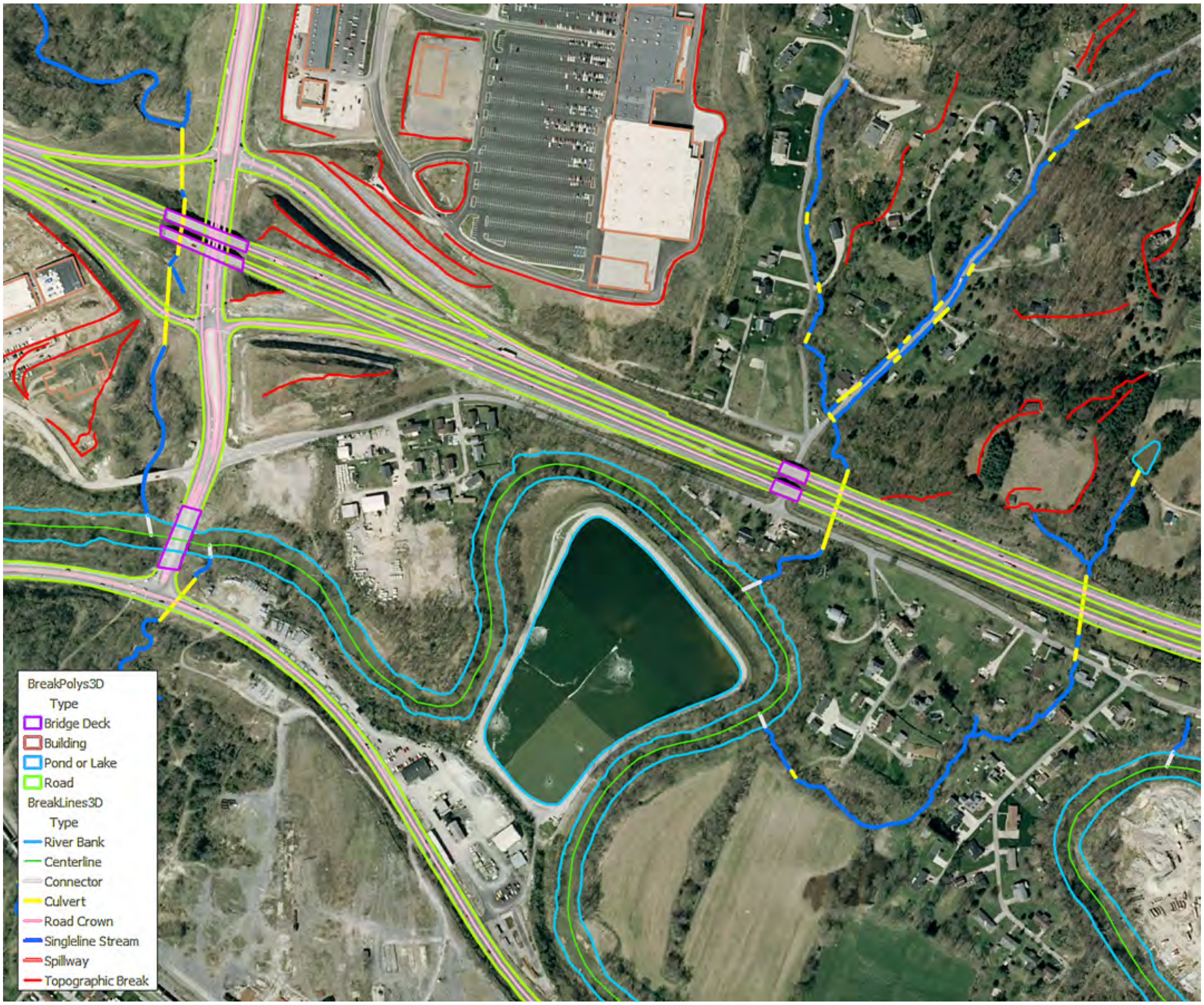


Figure 8. Sample area overlaid with light detection and ranging-based breaklines and polygons. All of the breaklines depicted were compiled directly from the light detection and ranging surface with the ortho imagery as reference support. Although many of the breaklines depicted are not directly related to hydrologic mapping, the graphic demonstrates the variety of breaklines that can be produced from only light detection and ranging. Image courtesy of the West Virginia State Address and Mapping Board, 2004. Breaklines developed from light detection and ranging data by the Earth Resources Observation and Science Center, 2010.

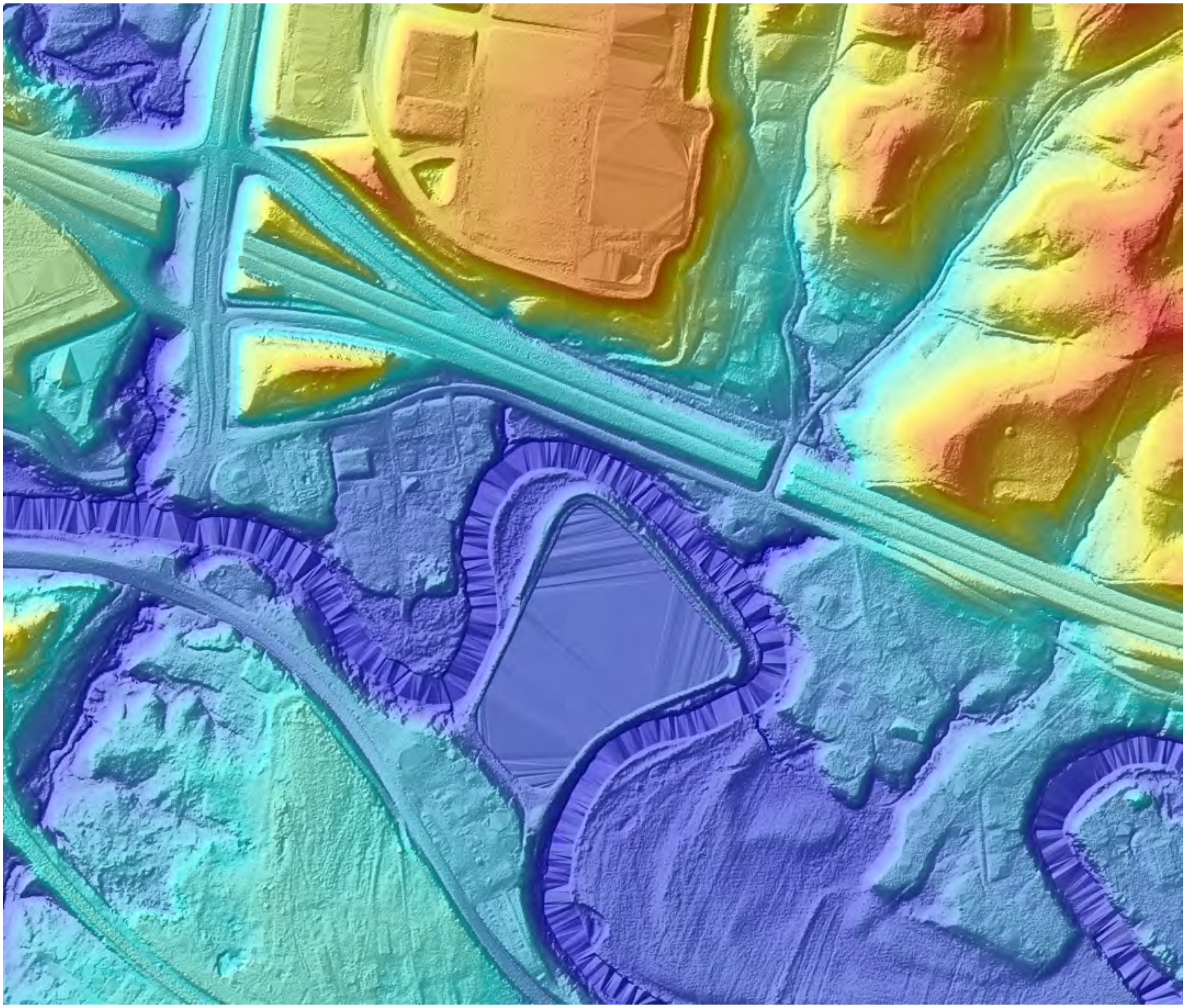


Figure 9. Pure light detection and ranging digital elevation model. This surface is created solely from the light detection and ranging points. No breaklines or other ancillary data was used to produce this surface. The unnatural appearance of the water surfaces demonstrates the critical need for digital elevation models to be hydro-flattened. Light detection and ranging data courtesy of Cabell County, West Virginia, 2009. Digital elevation model developed from light detection and ranging data by the Earth Resources Observation and Science Center, 2010.

Figure 10. Hydro-flattened light detection and ranging digital elevation model. The waterbody surfaces have been flattened by including only breaklines for ponds and rivers shown in cyan with the light detection and ranging points in creation of the surface. The river centerline shown in green is included as it is needed to assign elevations to the river banks. Light detection and ranging data courtesy of Cabell County, West Virginia, 2009. Digital elevation model and breaklines developed from light detection and ranging data by the Earth Resources Observation and Science Center, 2010.

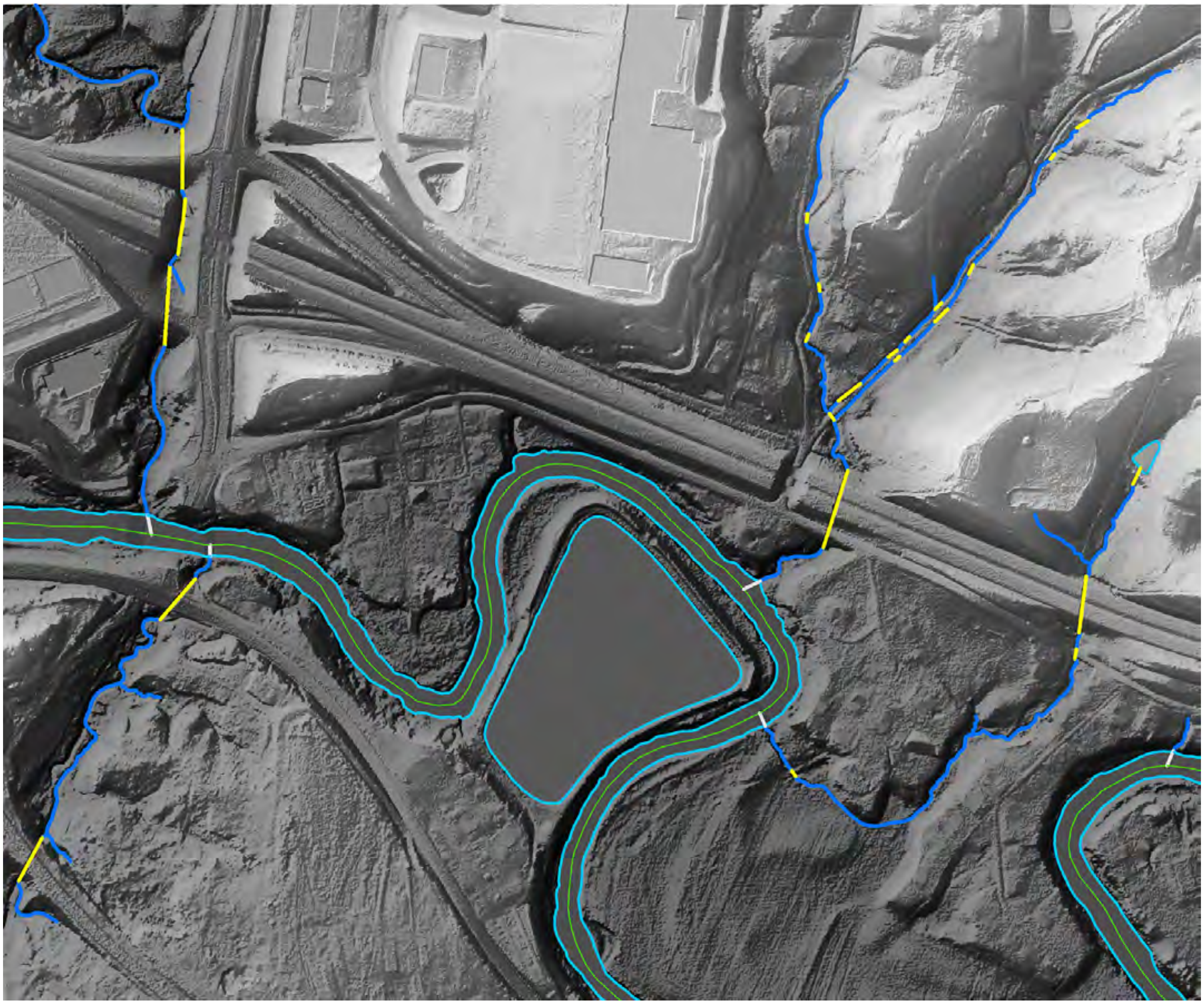


Figure 11. Hydro-enforced light detection and ranging digital elevation model. In this example, breaklines for single-line streams shown in blue, culverts shown in yellow, and connectors shown in white have been added to those for ponds and rivers, shown in cyan for surface generation. In this digital elevation model, single-line drainages are cleanly but naturally defined in the surface, and the functional flow paths of water through culverts are incorporated by lowering the ground surface elevations over the culverts to the level of the stream drainage. As in figure 10, the river centerline shown in green is also shown as it is required to assign elevations to the river bank lines. Light detection and ranging data courtesy of Cabell County, West Virginia, 2009. Digital elevation model and breaklines developed from light detection and ranging data by the Earth Resource Observation and Science Center, 2010.

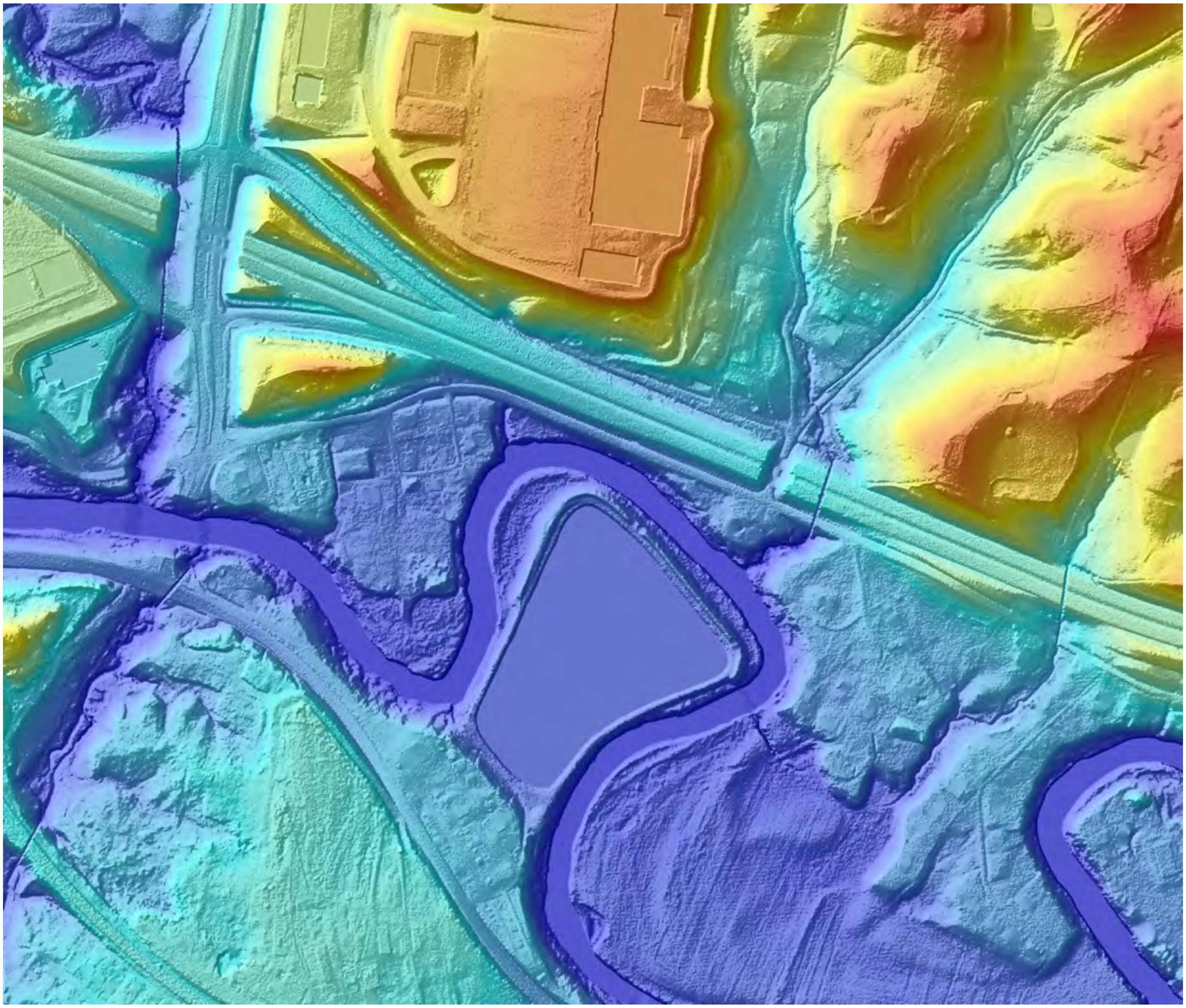
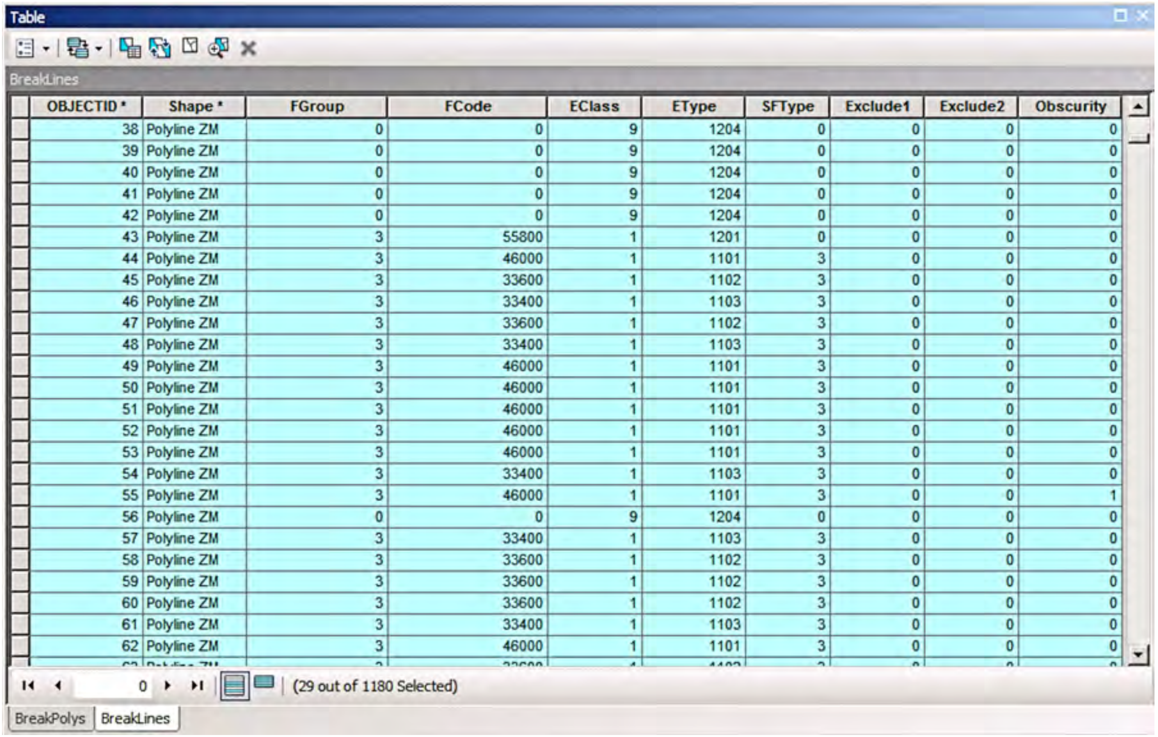
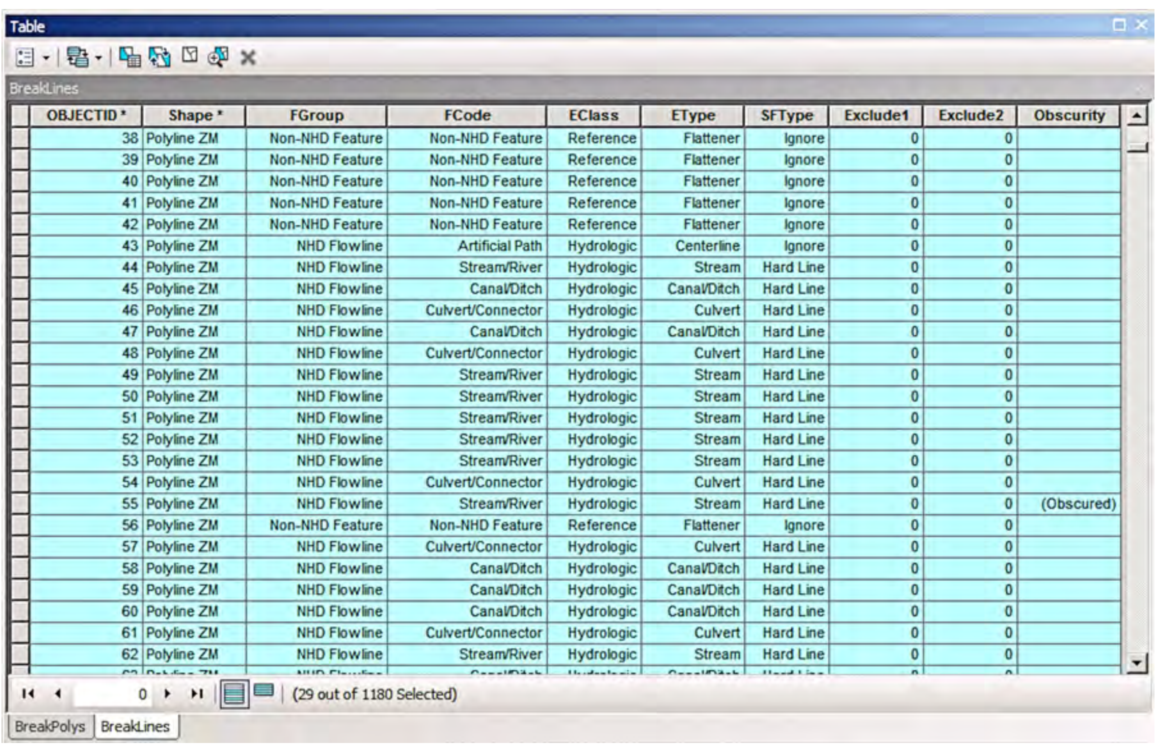


Figure 12. Colorized version of the hydro-enforced digital elevation model. This is the same surface shown in figure 11, with the breaklines removed for clearer depiction of the hydro-enforcement modifications to the surface. Light detection and ranging data courtesy of Cabell County, West Virginia, 2009. Digital elevation model developed from light detection and ranging data by the Earth Resource Observation and Science Center, 2010.



OBJECTID *	Shape *	FGroup	FCode	EClass	EType	SFType	Exclude1	Exclude2	Obscurity
38	Polyline ZM	0	0	9	1204	0	0	0	0
39	Polyline ZM	0	0	9	1204	0	0	0	0
40	Polyline ZM	0	0	9	1204	0	0	0	0
41	Polyline ZM	0	0	9	1204	0	0	0	0
42	Polyline ZM	0	0	9	1204	0	0	0	0
43	Polyline ZM	3	55800	1	1201	0	0	0	0
44	Polyline ZM	3	46000	1	1101	3	0	0	0
45	Polyline ZM	3	33600	1	1102	3	0	0	0
46	Polyline ZM	3	33400	1	1103	3	0	0	0
47	Polyline ZM	3	33600	1	1102	3	0	0	0
48	Polyline ZM	3	33400	1	1103	3	0	0	0
49	Polyline ZM	3	46000	1	1101	3	0	0	0
50	Polyline ZM	3	46000	1	1101	3	0	0	0
51	Polyline ZM	3	46000	1	1101	3	0	0	0
52	Polyline ZM	3	46000	1	1101	3	0	0	0
53	Polyline ZM	3	46000	1	1101	3	0	0	0
54	Polyline ZM	3	33400	1	1103	3	0	0	0
55	Polyline ZM	3	46000	1	1101	3	0	0	1
56	Polyline ZM	0	0	9	1204	0	0	0	0
57	Polyline ZM	3	33400	1	1103	3	0	0	0
58	Polyline ZM	3	33600	1	1102	3	0	0	0
59	Polyline ZM	3	33600	1	1102	3	0	0	0
60	Polyline ZM	3	33600	1	1102	3	0	0	0
61	Polyline ZM	3	33400	1	1103	3	0	0	0
62	Polyline ZM	3	46000	1	1101	3	0	0	0

Figure 13. Sample breakline attribute table with codes displayed.



OBJECTID *	Shape *	FGroup	FCode	EClass	EType	SFType	Exclude1	Exclude2	Obscurity
38	Polyline ZM	Non-NHD Feature	Non-NHD Feature	Reference	Flattener	Ignore	0	0	
39	Polyline ZM	Non-NHD Feature	Non-NHD Feature	Reference	Flattener	Ignore	0	0	
40	Polyline ZM	Non-NHD Feature	Non-NHD Feature	Reference	Flattener	Ignore	0	0	
41	Polyline ZM	Non-NHD Feature	Non-NHD Feature	Reference	Flattener	Ignore	0	0	
42	Polyline ZM	Non-NHD Feature	Non-NHD Feature	Reference	Flattener	Ignore	0	0	
43	Polyline ZM	NHD Flowline	Artificial Path	Hydrologic	Centerline	Ignore	0	0	
44	Polyline ZM	NHD Flowline	Stream/River	Hydrologic	Stream	Hard Line	0	0	
45	Polyline ZM	NHD Flowline	Canal/Ditch	Hydrologic	Canal/Ditch	Hard Line	0	0	
46	Polyline ZM	NHD Flowline	Culvert/Connector	Hydrologic	Culvert	Hard Line	0	0	
47	Polyline ZM	NHD Flowline	Canal/Ditch	Hydrologic	Canal/Ditch	Hard Line	0	0	
48	Polyline ZM	NHD Flowline	Culvert/Connector	Hydrologic	Culvert	Hard Line	0	0	
49	Polyline ZM	NHD Flowline	Stream/River	Hydrologic	Stream	Hard Line	0	0	
50	Polyline ZM	NHD Flowline	Stream/River	Hydrologic	Stream	Hard Line	0	0	
51	Polyline ZM	NHD Flowline	Stream/River	Hydrologic	Stream	Hard Line	0	0	
52	Polyline ZM	NHD Flowline	Stream/River	Hydrologic	Stream	Hard Line	0	0	
53	Polyline ZM	NHD Flowline	Stream/River	Hydrologic	Stream	Hard Line	0	0	
54	Polyline ZM	NHD Flowline	Culvert/Connector	Hydrologic	Culvert	Hard Line	0	0	
55	Polyline ZM	NHD Flowline	Stream/River	Hydrologic	Stream	Hard Line	0	0	(Obscured)
56	Polyline ZM	Non-NHD Feature	Non-NHD Feature	Reference	Flattener	Ignore	0	0	
57	Polyline ZM	NHD Flowline	Culvert/Connector	Hydrologic	Culvert	Hard Line	0	0	
58	Polyline ZM	NHD Flowline	Canal/Ditch	Hydrologic	Canal/Ditch	Hard Line	0	0	
59	Polyline ZM	NHD Flowline	Canal/Ditch	Hydrologic	Canal/Ditch	Hard Line	0	0	
60	Polyline ZM	NHD Flowline	Canal/Ditch	Hydrologic	Canal/Ditch	Hard Line	0	0	
61	Polyline ZM	NHD Flowline	Culvert/Connector	Hydrologic	Culvert	Hard Line	0	0	
62	Polyline ZM	NHD Flowline	Stream/River	Hydrologic	Stream	Hard Line	0	0	

Figure 14. Sample breakline attribute table with labels displayed.

Table

BreakPolys

OBJECTID *	Shape *	FGroup	FCode	EClass	EType	SFType	Exclude1	Exclude2	Obscurity
70	Polygon ZM	NHD Area	Bridge Deck	Manmade	Bridge Deck	Hard Replace	0	0	
72	Polygon ZM	NHD Area	Bridge Deck	Manmade	Bridge Deck	Hard Replace	0	0	
73	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
75	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
76	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
77	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
78	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
79	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
80	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
82	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
74	Polygon ZM	NHD Area	Swamp/Marsh	Reference	Swamp/ Marsh	Ignore	0	0	
83	Polygon ZM	NHD Area	Swamp/Marsh	Reference	Swamp/ Marsh	Ignore	0	0	

0 (12 out of 152 Selected)

BreakPolys

Figure 15. Sample breakpoly attribute table with codes displayed.

Table

BreakPolys

OBJECTID *	Shape *	FGroup	FCode	EClass	EType	SFType	Exclude1	Exclude2	Obscurity
70	Polygon ZM	NHD Area	Bridge Deck	Manmade	Bridge Deck	Hard Replace	0	0	
72	Polygon ZM	NHD Area	Bridge Deck	Manmade	Bridge Deck	Hard Replace	0	0	
73	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
75	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
76	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
77	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
78	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
79	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
80	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
82	Polygon ZM	NHD Waterbody	Lake/Pond	Hydrologic	Lake/Pond	Hard Replace	0	0	
74	Polygon ZM	NHD Area	Swamp/Marsh	Reference	Swamp/ Marsh	Ignore	0	0	
83	Polygon ZM	NHD Area	Swamp/Marsh	Reference	Swamp/ Marsh	Ignore	0	0	

0 (12 out of 152 Selected)

BreakPolys

Figure 16. Sample breakpoly attribute table with labels displayed.

Figure 17. National Hydrography Dataset and light detection and ranging-based breaklines. This image demonstrates how similar yet better positioned and more detailed the light detection and ranging-based breaklines are than the National Hydrography Dataset linework. Image courtesy of the West Virginia State Address and Mapping Board, 2004. Breaklines developed from light detection and ranging data by the Earth Resources Observation and Science Center, 2010. National Hydrography Dataset courtesy of the National Geospatial Program.

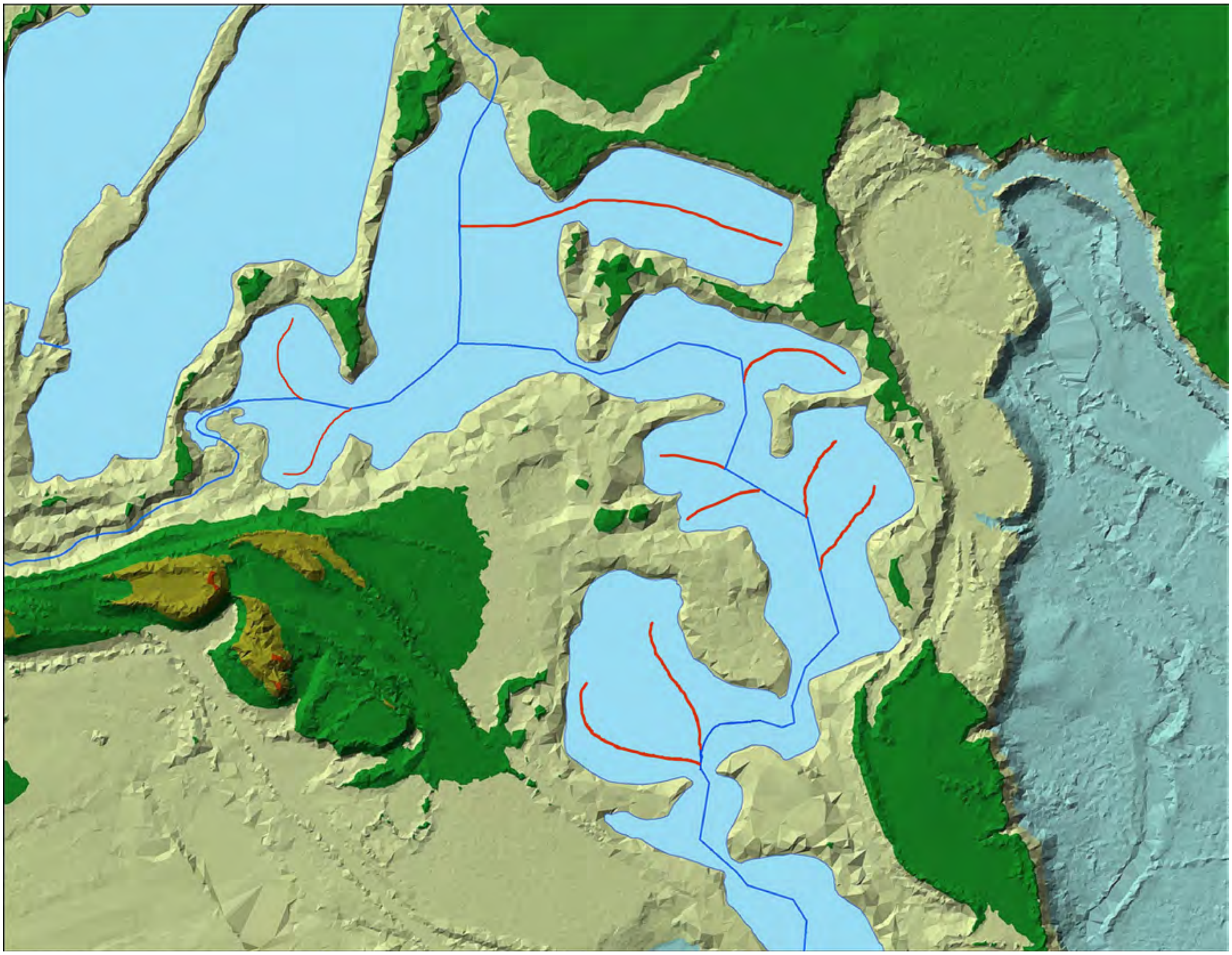


Figure 18. Example of flatteners. Standard center flowlines are shown in blue. Lines highlighted in red are flatteners, used solely to insure complex bank line vertices are assigned appropriate elevation values. They do not represent any actual hydrologic feature or function. Light detection and ranging data courtesy of North Carolina Emergency Management, 2014. Digital elevation model and breaklines developed from light detection and ranging data by the Earth Resources Observation and Science Center, 2014.

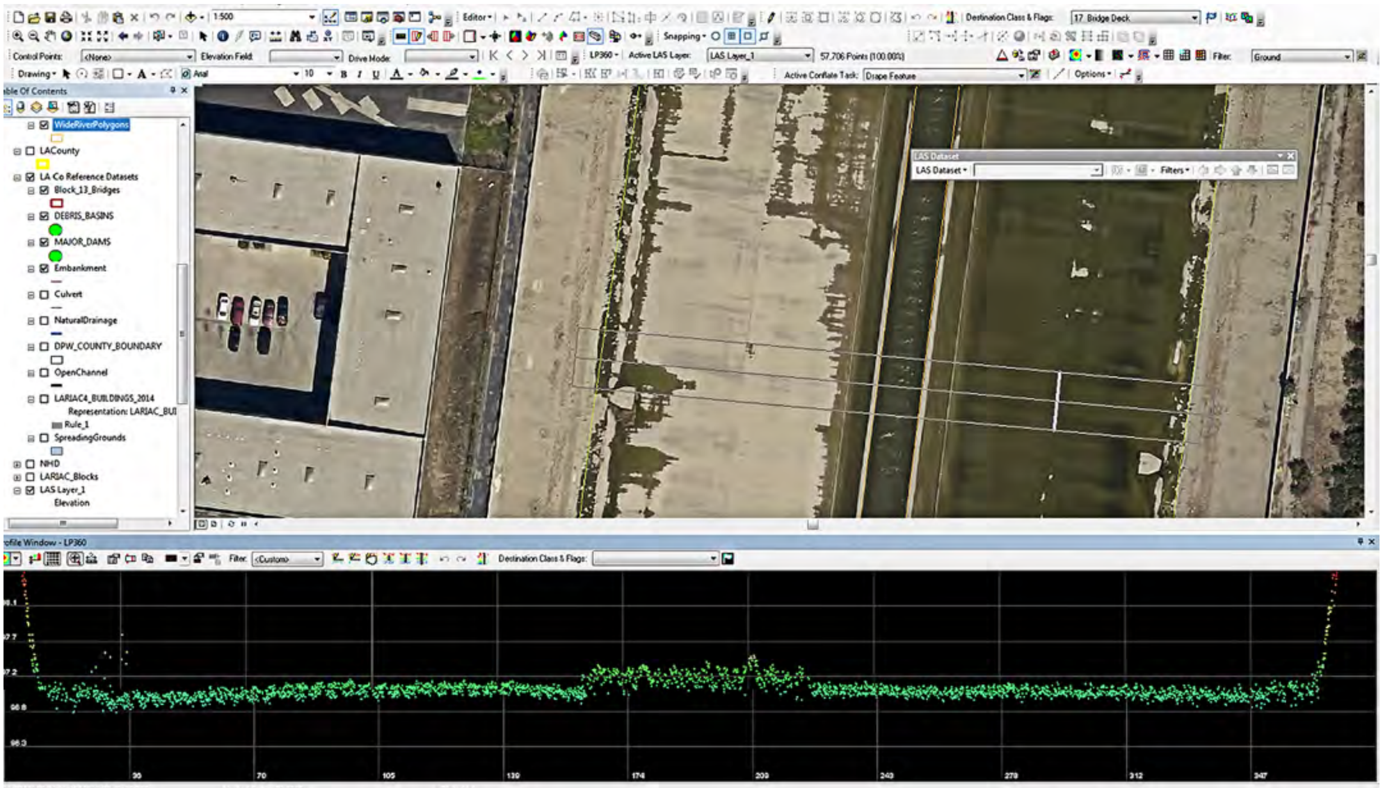


Figure 19. Example of a large channelized river, with a cross-section view. This is a portion of the Los Angeles River. Image courtesy of Los Angeles Regional Imagery Consortium, 2011.

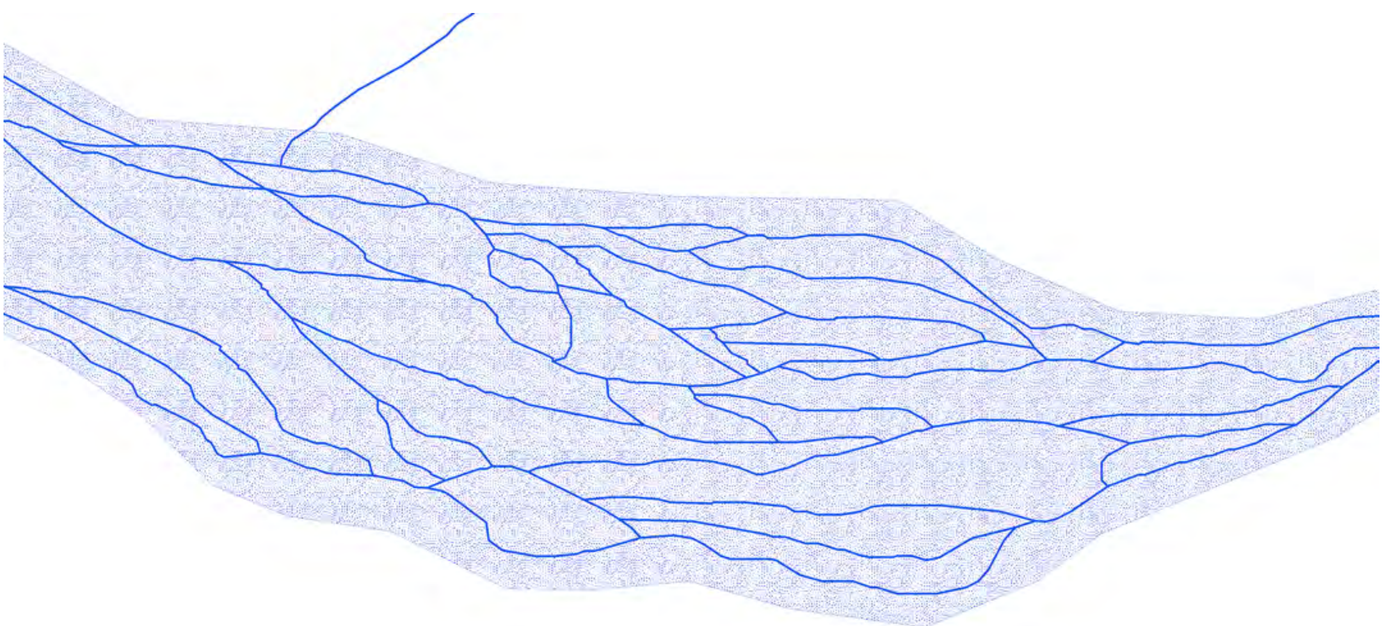


Figure 20. Example of a braided stream area (EType 1402). Shown as the light blue background polygon, this feature defines an area dense with stream braids depicted in darker blue lines. There are no explicit rules for how this polygon should be delineated; the data producer is to exercise their best professional judgement. This feature is for elevation reference. It is not used in the National Hydrography Dataset and has no National Hydrography Dataset equivalent.

Glossary

Note: Many of the following definitions are from Maune (2007) and American Society for Photogrammetry and Remote Sensing (ASPRS) (2014) 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. *See* precision.

- **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) (Federal Geographic Data Committee, 1998) 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. $ACC_r = 1.7308 * RMSE_r$. *See* 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. $ACC_z = 1.9600 * RMSE_z$. *See* RMSE$_z$.
- **horizontal accuracy** The horizontal (radial) component of the positional accuracy of a dataset with respect to a horizontal datum, at a specified confidence level. *See* accuracy$_r$.
- **local accuracy** The uncertainty in the coordinates of points with respect to coordinates of other directly connected, adjacent points at the 95-percent confidence level.
- **network accuracy** The uncertainty in the coordinates of mapped points with respect to the geodetic datum at the 95-percent confidence level.
- **positional accuracy** The accuracy at the 95-percent confidence level of the position of features, including horizontal and vertical positions, with respect to horizontal and vertical datums.
- **relative accuracy** A measure of variation in point-to-point accuracy in a dataset. In light detection and ranging (lidar), this term may also specifically mean the positional agreement between points within a swath, 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 at a specified confidence level or percentile. *See* accuracy$_z$.

aggregate nominal pulse density (ANPD) A variant of nominal pulse density that expresses the total expected or actual density of pulses located in a specified unit area resulting from multiple passes of the lidar instrument, or a single pass of a platform with multiple lidar instruments, over the same target area. In all other respects, ANPD is identical to nominal pulse density (NPD). In single coverage collection, ANPD and NPD will be equal. *See* aggregate nominal pulse spacing, nominal pulse density, nominal pulse spacing.

aggregate nominal pulse spacing (ANPS) A variant of nominal pulse spacing that expresses the typical or average lateral distance between pulses in a lidar dataset resulting from multiple passes of the lidar instrument, or a single pass of a platform with multiple lidar instruments, over the same target area. In all other respects, ANPS is identical to nominal pulse spacing

(NPS). In single coverage collections, ANPS and NPS will be equal. *See* aggregate nominal pulse density, nominal pulse density, nominal pulse spacing.

aqueduct A structure designed to transport domestic or industrial water from a supply source to a distribution point, often by gravity.

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, artifacts are 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.

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, 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 Nonpreferred term. *See* bare-earth.

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

blunder A mistake resulting from carelessness or negligence.

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 and 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-dimensional (3D) 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, rivers, shorelines, dams, ridges, building footprints, and other locations) with abrupt surface changes. Although some hard breaklines are 3D breaklines, they are typically depicted as 2-dimensional (2D) breaklines because features such as shorelines and building footprints are normally depicted with series of x, y coordinates only, which are often digitized from digital orthophotos that include no elevation data.

See mass point.

bridge A structure carrying a road, path, railroad, canal, aircraft taxiway, or any other transit between two locations of higher elevation over an area of lower elevation. A bridge may traverse a river, ravine, road, railroad, or other obstacle. “Bridge” also includes but is not limited to aqueduct, drawbridge, flyover, footbridge, overpass, span, trestle, and viaduct. In mapping, the term “bridge” is distinguished from a roadway over a culvert in that a bridge is an elevated deck that is not underlain with earth or soil. *See* culvert, saddle.

C

calibration (lidar systems) The process of identifying and correcting for systematic errors in hardware, software, or data. Determining the systematic errors in a measuring device by comparing its measurements with the markings or measurements of a device that is considered correct. 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 instrument manufacturer.

- **data calibration** The lever arm calibration determines the sensor-to-GPS-antenna offset vector (the lever arm) components relative to the antenna phase center. The offset vector components are redetermined each time the sensor or aircraft GPS antenna are moved or repositioned. Because normal aircraft operations can induce slight variations in component mounting, the components are normally field calibrated for each project, or even daily, to determine corrections to the roll, pitch, yaw, and scale calibration parameters.

calibration point Nonpreferred term. *See* control point.

cell (pixel) A single element of a raster dataset. Each cell contains a single numeric value of information representative of the area covered by the cell. Although the terms "cell" and "pixel" are synonymous, in this specification "cell" is used in reference to nonimage rasters such as digital elevation models (DEMs), whereas "pixel" is used in reference to image rasters such as lidar intensity images.

check point (checkpoint) A surveyed point (*x,y* or *x,y,z*) used to estimate the positional accuracy of a geospatial dataset against an independent source of greater accuracy. Check points are independent from, and may never be used as, control points on the same project.

classification (of lidar) The classification of lidar data 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 man-made features, and objects of interest.

confidence level The percentage of points within a dataset that are estimated to meet the stated accuracy; for example, accuracy reported at the 95-percent confidence level means that 95 percent of the positions in the dataset will have an error with respect to true ground position that are equal to or smaller than the reported accuracy value.

consolidated vertical accuracy (CVA) Replaced by the term vegetated vertical accuracy (VVA) in this specification, CVA is the term used by the National Digital Elevation Program (NDEP) guidelines for vertical accuracy at the 95th percentile in all land cover categories combined (NDEP, 2004). *See* percentile, vegetated vertical accuracy.

control point (calibration point) A surveyed point used to geometrically adjust a lidar dataset to establish its positional accuracy relative to the real world. Control points are independent from, and may never be used as, check points on the same project.

CONUS Continental United States, the conterminous 48 States.

culvert A tunnel carrying a stream or open drainage under a road or railroad or through another type of obstruction to natural drainage. 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 data coverage caused by surface nonreflectance 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 four times the ANPS, squared, measured using first returns only, is considered to be a data void.

datum A set of reference points on the Earth's surface against which position measurements are made, and (usually) 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 [NAD 83]) 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 [NAVD 88]) are used to 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 resolution The linear size of each cell of a raster DEM. Features smaller than the cell size cannot be explicitly represented in a raster model. DEM resolution may also be referred to as cell size, grid spacing, or ground sample distance.

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 man-made 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 DEMs 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 3D modeling and simulation.

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

- In some countries, DTMs are synonymous with DEMs, representing the bare-earth terrain with uniformly spaced *z*-values, as in a raster.
- As used in the United States, a "DTM" is a vector dataset composed of 3D breaklines and irregularly spaced 3D mass points, typically created through stereo photogrammetry, that characterize the shape of the bare-earth terrain. Breaklines more precisely delineate linear features whose shape and location would otherwise be lost. A DTM is not a surface model and its component elements are discrete and not continuous; a TIN or DEM surface must be derived from the DTM. Surfaces derived from DTMs can represent distinctive terrain features much better than those generated solely from gridded elevation measurements. A lidar dataset combined with ancillary breaklines is also considered a DTM.

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

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:

$$H = h - N,$$

where

h is equal to the ellipsoid height and
N is equal to the geoid height.

F

first return (first-return) The first important measurable part of a return lidar pulse.

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

fundamental vertical accuracy (FVA) Replaced by the term nonvegetated vertical accuracy (NVA), in this specification, FVA is the term used by the National Digital Elevation Program (NDEP) guidelines for vertical accuracy at the 95-percent confidence level in open terrain only where errors should approximate a normal error distribution. *See* nonvegetated vertical accuracy, accuracy, confidence level.

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.

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.

horizontal accuracy Positional accuracy of a dataset with respect to a horizontal datum. According to the “National Standards for Spatial Data Accuracy” (Federal Geographic Data Committee, 1998), horizontal (radial) accuracy at the 95-percent confidence level is defined as ACC_r.

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, and sewers) to predict flood levels and manage water resources. Hydraulic models are based on computations involving liquids under pressure, and many other definitions of hydraulic modeling exist that are not associated 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, rivers, and lakes. Digital elevation data are used as part of hydrologic modeling.

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 isolated sinks or pits. The only sinks that are retained are the real ones on the landscape. Although 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 and (or) links among basins and (or) catchments can be known for large areas.

hydrologically flattened (hydro-flattened) Processing of a lidar-derived surface (DEM or TIN) so that mapped waterbodies, streams, rivers, reservoirs, and other cartographically polygonal water surfaces are flat and, where appropriate, level from bank to bank. Additionally, surfaces of streams, rivers, and long reservoirs demonstrate a gradient change in elevation along their length, which is consistent with their natural behavior and the surrounding topography. In traditional maps that are compiled photogrammetrically, this process is accomplished automatically through the inclusion of measured breaklines in the 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 waterbodies, streams, rivers, and ponds. These breaklines establish elevations for the water surfaces that are consistent with the surrounding topography and produce aesthetically acceptable water surfaces in the final 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 waterbodies so that lakes and reservoirs are level and so that streams and rivers 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 and rivers would be 3D 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 many factors such as the instantaneous setting of the instrument's Automatic Gain Control and angle of incidence and thus cannot be equated to a true measure of energy for discrete return systems. 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 grayscale 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 electromagnetic 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, lidar intensity images must be interpreted and analyzed with unusually high care and skill.

L

LAS A public file format for the interchange of 3D point data between data users. The file extension is .las (ASPRS, 2011).

last return The last important measurable part of a return lidar pulse.

lattice A 3D vector 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 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, lever arms are positioned 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 GPS, IMU, and the instrument itself, allows the derivation of the 3D point location of the reflecting target's location.

lift A lift is a single takeoff and landing cycle for a collection platform (fixed or rotary wing) within an aerial data collection project, often lidar.

local accuracy *See* accuracy.

M

mass point(s) Irregularly spaced points, each with *x*, *y*, *z* coordinates, typically (but not always) used to form a TIN. When generated manually, mass points are ideally chosen to depict the most significant variations in the slope or aspect of TIN triangles; however, when generated automatically (for example, by lidar), mass point spacing and pattern depend upon the characteristics of the technologies used to acquire the data. Mass points are usually used in conjunction with breaklines. *See* breakline.

metadata Any information that is descriptive or supportive of a geospatial dataset, including 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).

monotonic In mathematics, a function that varies such that it either increases or decreases, but never both. As used in this specification, it describes a hydrographic breakline that continuously flows either level or downhill, but never uphill.

N

nominal pulse density (NPD) A common measure of the density of a lidar dataset; NPD is the typical or average number of pulses within a specified areal unit. NPD is typically expressed as pulses per square meter. This value is predicted in mission planning and empirically calculated from the collected data, using only the first (or last) return points as surrogates for pulses. As used in this specification, NPD refers to single swath, single instrument data, whereas ANPD describes the overall pulse density resulting from multiple passes of the lidar instrument, or a single pass of a platform with multiple lidar instruments, over the same target area. NPD is more commonly used in high-density collections (greater than or equal to 1 pulses per square meter [pls/m^2]), with its inverse, NPS, being used in low-density collections (less than or equal to 1 pls/m^2). Assuming meters are being used in both expressions, NPD can be calculated from NPS using the formula $NPD = 1/NPS^2$. *See* aggregate nominal pulse density, aggregate nominal pulse spacing, nominal pulse spacing.

nominal pulse spacing (NPS) A common measure of the density of a lidar dataset, NPS is the typical or average lateral distance between pulses in a lidar dataset, typically expressed in meters and most simply calculated as the square root of the average area per first return point. This value is predicted in mission planning and empirically calculated from the collected data, using only the first (or last) return points as surrogates for pulses. As used in this specification, NPS refers to single swath, single instrument data, whereas ANPS describes the overall pulse spacing resulting from multiple passes of the lidar instrument, or a single pass of a platform with multiple lidar instruments, over the same target area. NPS is more commonly used in low-density collections (greater than or equal to 1 m NPS), with its inverse, NPD, being used in high-density collections (less than 1 m NPS). Assuming meters are being used in both expressions, NPS can be calculated from NPD using the formula $NPS = 1/\sqrt{NPD}$. See aggregate nominal pulse density, aggregate nominal pulse spacing, nominal pulse density.

nonvegetated vertical accuracy (NVA) Replaces fundamental vertical accuracy (FVA). The vertical accuracy at the 95-percent confidence level in nonvegetated open terrain, where errors should approximate a normal distribution. See fundamental vertical accuracy.

O

overage Those parts of a swath that are not necessary to form a complete single, nonoverlapped, gap-free coverage with respect to the adjacent swaths. The nontenderloin parts of a swath. In collections designed using multiple coverage, overage are the parts of the swath that are not necessary to form a complete nonoverlapped coverage at the planned depth of coverage. In LAS specification version 1.4–R13 (ASPRS, 2011), these points are identified by using the incorrectly named “overlap” bit flag. *See* overlap, tenderloin.

overlap Any part of a swath that also is covered by any part of any other swath. The term overlap is incorrectly used in LAS specification version 1.4–R13 (ASPRS, 2011) to describe the bit flag intended to identify overage points. *See* overage, tenderloin.

P

penstock A structure designed to convey water into the turbine of a hydro-electric generating plant. Typically the main pipes within a large hydro-electric dam.

percentile A measure used in statistics indicating the value below which a given percentage of observations (absolute values of errors) in a group of observations fall. For example, the 95th percentile is the value (or score) below which 95 percent of the observations may be found. There are different approaches to determining percentile ranks and associated values. This specification recommends the use of the following equations for computing percentile rank and percentile as the most appropriate for estimating the vegetated vertical accuracy (VVA). Note that percentile calculations are based on the absolute values of the errors because it is the magnitude of the errors, not the sign, which is of concern. The percentile rank (n) is first calculated for the desired percentile using the following equation:

$$n = (((\frac{P}{100}) * (N - 1)) + 1) \tag{1}$$

where:

n is the rank of the observation that contains the *Pth* percentile,

P is the proportion (of 100) at which the percentile is desired (for example, 95 for 95th percentile), and

N is the number of observations in the sample dataset.

Once the rank of the observation is determined, the percentile (Q_p) can then be interpolated from the upper and lower observations using the following equation:

$$Q_p = (A[n_w] + (n_d * (A[n_w + 1] - A[n_w]))) \qquad (2)$$

where:

Q_p is the *Pth* percentile; the value at rank *n*;
A is an array of the absolute values of the samples, indexed in ascending order from 1 to *N*;
$A[i]$ is the sample value of array *A* at index *i* (for example, n_w or n_d). *i* must be an integer between 1 and *N*;
n is the rank of the observation that contains the *Pth* percentile;
n_w is the whole number component of *n* (for example, 3 of 3.14); and
n_d is the decimal component of *n* (for example, 0.14 of 3.14).

pixel *See* cell.

playa An undrained desert basin that periodically fills with water to form a temporary lake. Playas drain directly into the ground. They can often be identified by having apparent inlet channels but no outlets, and with flat and level floors.

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

point cloud One of the fundamental types of geospatial data (others being vector and raster), a point cloud is a large set of 3D 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 are orders of magnitude more dense 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.

See raster, vector.

precision (repeatability) The closeness with which measurements agree with each other, even though they may all contain a systematic bias. *See* accuracy.

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

preprocessing In lidar, the preprocessing of data most commonly refers to those steps used in converting the collected GPS, IMU, instrument, and ranging information into interpretable *X-Y-Z* point data, including 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, including point classification, feature extraction (for example, building footprints, hydrographic features, and others), tiling, and generation of derivative products (DEMs, DSMs, intensity images, and others).

R

raster One of the fundamental types of geospatial data (others being vector and point cloud), a raster is an array of cells (or pixels) that each contain a single piece of numeric information representative of the area covered by the cell. Raster datasets are spatially continuous; with respect to DEMs, this quality creates a surface from which information can be extracted from any location. As spatial arrays, rasters are always rectangular; cells are most often square.

Co-located rasters can be stored in a single file as layers, as with color digital images. *See* raster, vector.

resolution The smallest unit a sensor can detect or the smallest unit a raster DEM depicts. The degree of fineness to which a measurement can be made. "Resolution" is also used to describe the linear size of an image pixel or raster cell.

root mean square difference (RMSD) The square root of the average of the set of squared differences between two dataset coordinate values taken at identical locations. RMSD differentiates from root mean square error (RMSE) because neither dataset is known to be more or less accurate than the other, and the differences cannot be regarded as errors. RMSD is used in lidar when assessing relative accuracy, both intraswath and interswath. *See* root mean square error.

root mean square error (RMSE) The square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The RMSE is used to estimate the absolute accuracy of both horizontal and vertical coordinates when standard or accepted values are known, as with GPS-surveyed check points of higher accuracy than the data being tested. In the United States, the independent source of higher accuracy is expected to be at least three times more accurate than the dataset being tested.

- **RMSE$_r$** The horizontal root mean square error in the radial direction that includes both *x* and *y* coordinate errors.

$$\sqrt{(RMSE_x{}^2 + RMSE_y{}^2)} \tag{3}$$

where:

$RMSE_x$ is the RMSE in the *x* direction, and
$RMSE_y$ is the RMSE in the *y* direction.

- **RMSE$_x$** The horizontal root mean square error in the *x* direction (easting).

$$\sqrt{\sum \frac{(x_n - x'_n)^2}{N}} \tag{4}$$

where:

x_n is the set of *N x* coordinates being evaluated,
x'_n is the corresponding set of check point *x* coordinates for the points being evaluated,
N is the number of *x* coordinate check points, and
n is the identification number of each check point from 1 through *N*.

- **RMSE$_y$** The horizontal root mean square error in the *y* direction (northing).

$$\sqrt{\sum \frac{(y_n - y'_n)^2}{N}} \tag{5}$$

where:

y_n is the set of *N y* coordinates being evaluated,
y'_n is the corresponding set of check point *y* coordinates for the points being evaluated,
N is the number of *y* coordinate check points, and
n is the identification number of each check point from 1 through *N*.

- **RMSE$_z$** The vertical root mean square error in the *z* direction (elevation).

$$\sqrt{\sum \frac{(z_n - z'_n)^2}{N}} \tag{6}$$

where:

z_n is the set of N z values (elevations) being evaluated,

z'_n is the corresponding set of check point elevations for the points being evaluated,

N is the number of z check points, and

n is the identification number of each check point from 1 through N.

S

saddle The lowest area between two opposing higher terrain features, usually connecting two areas of lower terrain, as in a mountain pass. Used in this specification to reference the area exposed by the removal or exclusion of a bridge deck from a DEM. *See* bridge.

siphon A structure designed to convey water by gravitational force over, or under, an obstruction. Often seen as vertical pipes in smaller ponds with earthen dams that convey overflow water under the dam.

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 factors:

- instrument design (oscillating mirrors),
- mission planning (difference between along-track and cross-track pulse spacing), and
- in-flight attitude variations (roll, pitch, and yaw).

standard deviation A measure of spread or dispersion of a sample of errors around the sample mean error. It is a measure of precision, rather than accuracy; the standard deviation does not account for uncorrected systematic errors.

supplemental vertical accuracy (SVA) Merged into the Vegetated Vertical Accuracy (VVA) in this specification, SVA is the NDEP guidelines term for reporting the vertical accuracy at the 95th percentile in each separate land cover category where vertical errors may not follow a normal error distribution. *See* percentile, vegetated vertical accuracy.

swath The data resulting from a single flightline of collection. Swaths can be considered as one of five general types:

- project: originally planned to cover the project area.
- cross-tie: originally planned and within the project area, but intended for calibration/boresighting purposes only.
- calibration: data collected for calibration/boresighting purposes only, usually over the base airport, and often not within the project area.
- fill-in: additional swaths collected to fill unplanned gaps or areas of low data density discovered in the planned project area collection.
- other: any swath that does not meet the above definitions.

See flightline.

systematic error An error whose algebraic sign and, to some extent, magnitude bears a fixed relation to some condition or set of conditions. Systematic errors follow some fixed pattern and are introduced by data collection procedures, processing, or given datum.

T

tenderloin The central part of the swath that, when combined with adjacent swath tenderloins, forms a complete, single, nonoverlapped, gap-free coverage. In collections designed using multiple coverage, tenderloins are the parts of the swath necessary to form a complete nonoverlapped, gap-free coverage at the planned depth of coverage. *See* overage, overlap.

topology The spatial relationship between geographic features in a common space. Examples particularly relevant to this specification include precise coincidence of ending and beginning vertices of lines in a continuous network (stream connectivity), and consistent line direction (from high to low) corresponding to streamflow direction.

triangulated irregular network (TIN) A vector data structure that partitions geographic space into contiguous, nonoverlapping triangles. In lidar, the vertices of each triangle are 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

uncertainty (of measurement) A parameter that characterizes the dispersion of measured values, or the range in which the "true" value most likely lies. It can also be defined as an estimate of the limits of the error in a measurement (where "error" is defined as the difference between the theoretically unknowable "true" value of a parameter and its measured value). Standard uncertainty refers to uncertainty expressed as a standard deviation.

V

vector One of the fundamental types of geospatial data (others being raster and point cloud), vectors include a variety of data structures that are geometrically described by *x*, *y*, and potentially *z* coordinates. Vector data subtypes include points, lines, and polygons. A DTM consisting of mass points and breaklines is an example of a vector dataset; a TIN is a vector surface. *See* point cloud, raster.

vegetated vertical accuracy (VVA) Replaces supplemental vertical accuracy (SVA) and CVA. An estimate of the vertical accuracy, based on the 95th percentile, in vegetated terrain where errors do not necessarily approximate a normal distribution. *See* percentile, nonvegetated vertical accuracy.

W

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

well-distributed For a dataset covering a rectangular area that has uniform positional accuracy, check points 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" [Federal Geographic Data Committee, 1998]). As related to this specification, these guidelines are applicable to each land cover class for which check points 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, and
- geometrically unreliable points near the edge of a swath.

Appendixes

Appendix 1. Common Data Upgrades

Appendix 1 contains a partial list of common upgrades, which is neither comprehensive nor exclusive.

- Independent third-party quality assurance/quality control by another contractor.
- Full Waveform collection and delivery.
- Additional Environmental Constraints.
  - Tidal coordination, flood stages, crop or plant growth cycles.
  - 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 grayscale, tiled).
  - Interpolation based on First Returns.
  - Interpolation based on All-Returns, summed.
- Detailed Classification (additional classes).
  - Class 3: Low vegetation.
  - Class 4: Medium Vegetation (use for single vegetation class).
  - Class 5: High Vegetation.
  - Class 6: Buildings, other man-made structures.
  - Class n: Additional classes or features as agreed upon in advance.
- Hydro-enforced digital elevation models (DEMs) as an additional deliverable.
- Hydro-conditioned DEMs as an additional deliverable.
- Breaklines (PolylineZ and PolygonZ) for additional hydrographic and topographic features.
  - Narrower double-line streams and rivers.
  - Single-line streams and rivers.
  - Smaller ponds.
  - Culverts and other drainage structures.
  - Retaining walls.
  - Hydrologic areas (for example, swamp or marsh).
  - Appropriate integration of additional features 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 before a funding commitment.

Appendix 2. Hydro-Flattening Reference

The subject of variations of light detection and ranging (lidar)-based digital elevation models (DEMs) is somewhat new and substantial diversity exists in the understanding of the topic across the industry. The material in this appendix 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 standard national DEM available through the U.S. Geological Survey's (USGS's) The National Map. The information presented in this appendix is not meant to supplant other reference materials and is not to be considered authoritative beyond its intended scope.

As used in this specification, "hydro-flattened" describes the specific type of DEM required by the USGS National Geospatial Program (NGP) for integration into the standard national DEM available through The National Map. Hydro-flattening is the process of creating a lidar-derived DEM in which water surfaces appear and behave as they would in traditional topographic DEMs created from photogrammetric digital terrain models (DTMs). A hydro-flattened DEM is a topographic DEM and is not to be confused with hydro-enforced or hydro-conditioned DEMs, which are hydrologic surfaces.

Traditionally, topography was depicted using contours on printed maps and, although modern computer technology provides superior alternatives, the contour map remains a popular and widely used product. The standard national DEM available through The National Map was initially developed as a topographic DEM from USGS contour maps and it remains the underlying source data for newly generated contours. To ensure that USGS contours continue to present the same type of information as they are updated, DEMs used to update the standard national DEM available through The National Map must also possess the same basic character as the existing standard national DEM available through The National Map.

A traditional topographic DEM such as the standard national DEM available through The National Map or the earlier National Elevation Dataset (NED) represents the actual ground surface, and hydrologic features are handled in established ways. Roadways crossing drainages passing through culverts remain in the surface model because they are part of the landscape (the culvert beneath the road is the man-made feature). Bridges, man-made structures above the landscape, are removed.

For many years, the source data for topographic raster DEMs were mass points and breaklines (collectively referred to as a DTM) compiled through photogrammetric compilation from stereographic aerial imagery. The DTM is converted into a triangulated irregular network (TIN) surface from which a raster DEM could be generated. Photogrammetric DTMs inherently contain breaklines that clearly define the edges of waterbodies, coastlines, and single- and double-line streams and rivers. These breaklines force the derived DEM to appear, and contours to behave, in specific ways: water surfaces appear flat, roadways are continuous when on the ground, and rivers are continuous under bridge locations; contours follow waterbody banks and cross streams are perpendicular to the centerline.

[Note: DEMs developed solely for orthophoto production may include bridges, because their presence prevents distortion in the image and reduces the amount of postprocessing for corrections of the final orthophotos. These are special-use DEMs and are not relevant to this specification.]

Computer technology allows hydraulic and hydrologic (H&H) modeling to be performed using digital DEM surfaces directly. For these applications, traditional topographic DEMs present a variety of problems that are solved through modification of the DEM surface. The "DEM Users' Manual" (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. 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 waterbodies 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 (H&H) 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.

Hydro-enforcement and hydro-conditioning are important and useful modifications of the traditional topographic DEM, but they produce hydrologic surfaces that are fundamentally different at a functional level. Hydrologic surfaces are identical to topographic surfaces in many respects but they differ significantly in specific ways. In a topographic DEM, roadways over culverts are included in the surface as part of the landscape. From a hydrologic perspective, however, these roadways create artificial impediments ("digital dams") to the drainages and introduce sinks (undrained areas) into the landscape. Similarly, topographic DEMs obviously cannot reflect the drainage routes provided by underground stormwater systems, hence topographic DEM surfaces will invariably include other sinks. For topographic mapping, sinks are of no consequence—it is actually desirable to know their locations—but they can introduce errors into hydrologic modeling results.

As lidar has largely replaced photogrammetric DTMs as the primary source of data for DEMs, a new complication has been introduced. Unlike the DTM, lidar data consist solely of mass points; breaklines are not automatically created during lidar data collection. In spite of the substantially higher density of mass points collected, lidar points alone are limited in their ability to precisely define the boundaries or locations of distinct linear features such as waterbodies, streams, and rivers. The lack of breaklines in the intermediate TIN data structure causes triangulation across waterbodies, producing a water surface filled with irregular, unnatural, and visually unappealing triangulation artifacts. These artifacts are then carried into the derived DEM and ultimately into contours developed from the National Elevation Dataset (NED). The representation of random irregular water surfaces in the NED is wholly unacceptable to the USGS–NGP and to users of the NED and its derivatives.

To achieve the same character and appearance of a traditional topographic DEM (or to develop a hydrologically enforced DEM) from lidar source data, breaklines must be developed separately using other techniques. These breaklines are then integrated with lidar points as a complete DTM or used to modify a DEM previously generated without breaklines.

Hydrologic DEMs usually require flattened water surfaces as well, hence the breaklines required for hydro-flattening the topographic DEM can be equally useful for all DEM types as well (*see* Note below). Additional breaklines (and lidar point classifications) are needed to efficiently generate hydro-enforced DEMs. If properly attributed, breaklines for all DEM treatments can be stored in a single set of feature classes.

The use of breaklines is the predominant method used for hydro-flattening, though other techniques may exist. The USGS–NGP does not require that breaklines be used for flattening but does require the delivery of breaklines for all flattened waterbodies and any other breaklines developed for each project (*see* the "Hydro-Flattening" section in the main report and this appendix for additional information).

[Note: Civil engineers and hydrologists may have requirements for the accuracy of water surface elevations. With respect to elevation data, the USGS–NGP's interest is in accurate and complete representation of land topography, not water surface elevations. Topographic lidar is known to be inconsistent and unreliable in water surface measurements, and water surface elevations fluctuate with tides, rainfall, and changes to man-made controls. It is therefore impractical to assert any accuracy for the water surface elevations in the NED, and the USGS–NGP imposes no requirement for absolute accuracy of water surface elevations in lidar and DEM deliveries.]

References Cited

Maune, D.F., 2007, Definitions, in Digital elevation model technologies and applications—The DEM users' manual, 2nd edition: Bethesda, Md., American Society for Photogrammetry and Remote Sensing, p. 535–564.

Appendix 3. Light Detection and Ranging Metadata Example


```
<?xml version="1.0" encoding="UTF-8"?>
<!--DOCTYPE metadata SYSTEM "fgdc-std-001-1998.dtd"-->
<metadata>
  <idinfo>
    <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 data</geoform>
      </citeinfo>
    </citation>
    <descript>
      <abstract>Geographic Extent: This dataset is light detection and ranging
        (lidar) point data, which encompasses a 1,000 meter buffer around
        Phelps and Dent Counties in Missouri, approximately 829 square miles.
        Dataset Description: This dataset consists of 457 lidar data 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 subswath files, each less than 2GB.
        Ground Conditions: water at normal levels; no unusual inundation;
        no snow; leaf off
      </abstract>
      <lidar>
        <ldrinfo>
          <ldrspec>U.S. Geological Survey (USGS) - National Geospatial Program
            (NGP) Lidar Base Specification v1.3
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          <ldrsens>Optech Gemini Airborne Laser Terrain Mappers (ALTM)</ldrsens>
          <ldrmaxnr>4</ldrmaxnr>
          <ldrnps>0.7071</ldrnps>
          <ldrdens>2</ldrdens>
          <ldranps>0.7071</ldranps>
          <ldradens>2</ldradens>
          <ldrfltht>3000</ldrfltht>
          <ldrfltsp>115</ldrfltsp>
          <ldrscana>26</ldrscana>
          <ldrscanr>40</ldrscanr>
          <ldrpulsr>120</ldrpulsr>
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          <ldrpulsw>3</ldrpulsw>
          <ldrwavel>1064</ldrwavel>
          <ldrmpia>0</ldrmpia>
          <ldrbmdiv>4.5</ldrbmdiv>
          <ldrswatw>1200</ldrswatw>
          <ldrswato>15</ldrswato>
          <ldrgeoid>National Geodetic Survey (NGS) Geoid12b</ldrgeoid>
        </ldrinfo>
        <ldraccur>
          <ldrchacc>0.5</ldrchacc>
          <rawnva>0.11</rawnva>
          <rawnvan>27</rawnvan>
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```

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    <laswheld>Withheld (ignore) points were identified in these files
      using the standard LAS Withheld bit flag
    </laswheld>
    <lasolap> Swath "overage" points were identified in these files using
      the standard LAS overlap bit flag
    </lasolap>
    <lasintrz>11-bit</lasintrz>
    <lasclass>
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      <clasitem>Undetermined/Unclassified</clasitem>
    </lasclass>
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      <clascode>2</clascode>
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    </lasclass>
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      <clascode>20</clascode>
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    </lasclass>
  </lasinfo>
</lidar>
<purpose>The purpose of these lidar data was to produce a high accuracy three
  dimensional (3D) hydro-flattened digital elevation model  (DEM) with a 1.0
  foot cell size. The data will be used by the Federal Emergency Management
  Agency (FEMA) for flood plain mapping. These raw lidar data were
  used to create classified lidar LAS files, intensity images, 3D breaklines,
  and to hydro-flattened DEMs as necessary.
</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.
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</descript>
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</timeperd>
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</status>
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    <northbc>38.000000</northbc>
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    <placekey>Phelps County</placekey>
    <placekey>Dent County</placekey>
    <placekey>Mark Twain National Forest</placekey>
  </place>
</keywords>
<accconst>No restrictions apply to this data.</accconst>
<useconst>None. However, users should be aware that temporal changes may
  have transpired 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.
</useconst>
<ptcontac>
  <cntinfo>
    <cntorgp>
      <cntorg>We Map 4U, Data Acquisition Department</cntorg>
      <cntper>Jane Smith</cntper>
    </cntorgp>
    <cntaddr>
```

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        <address>123 Main St.</address>
        <city>Anytown</city>
        <state>MO</state>
        <postal>61234</postal>
        <country>USA</country>
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      <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>
  </ptcontac>
  <native>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
  </native>
</idinfo>
<dataqual>
  <logic>Data cover the entire area specified for this project.</logic>
  <complete>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. No void areas or missing data
    exist.  The raw point data is of good quality and data meet fundamental
    vertical accuracy specifications.
  </complete>
  <posacc>
    <vertacc>
      <vertaccr>The specifications require that only nonvegetated vertical
        accuracy (NVA) be computed for raw lidar data swath files.
        The vertical accuracy was tested with 25 independent survey located
        in open terrain. These check points (check points) were not used in
        the calibration or post processing of the lidar data.
        The survey check points were distributed throughout the project.
        Specifications for this project require that the NVA be 25 centimeters
        (cm) or better AccuracyZ at 95-percent confidence level.
      </vertaccr>
      <qvertpa>
        <vertaccv>0.19 meters AccuracyZ at 95-percent confidence level
        </vertaccv>
        <vertacce>The NVA was tested using 25 independent survey located in
          open terrain.  The survey check points were distributed throughout
          the project area. The 25 independent check points were surveyed
          using the closed level loop 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 root mean square error vertical (RMSEz) was computed to be
          0.097 meters. AccuracyZ has been tested to meet 19.0 cm NVA at
          95-percent confidence level using (RMSEz * 1.9600) as defined by
          the National Standards for Spatial Data Accuracy (NSSDA); assessed
          and reported using American Society of Photogrammetry and Remote Sensing
          (ASPRS) Guidelines.
        </vertacce>
      </qvertpa>
    </vertacc>
```

```
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        <title>Ground Control for Phelps and Dent County, MO lidar project
        </title>
        <geoform>vector digital data and tabular data</geoform>
        <pubinfo>
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          <publish>Jiffy Survey, Inc., GPS department</publish>
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    <typesrc>CD-ROM</typesrc>
    <srctime>
      <timeinfo>
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        </sngdate>
      </timeinfo>
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    </srctime>
    <srccitea>Phelps_Co_lidar_gnd_ctrl</srccitea>
    <srccontr>This data source was used (along with the airborne Global Positioning
      System [GPS]/Inertial Measurement Unit [IMU] data) to georeference the lidar
      point data.
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        </title>
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            Center
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```
    <srccitea>Phelps-Dent_Co_NAIP_Imagery</srccitea>
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          <enddate>20100218</enddate>
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      <srccurr>ground condition</srccurr>
    </srctime>
    <srccitea>Phelps-Dent_Co_Lidar_Intensity_Imagery</srccitea>
    <srccontr>This data source was used (along with National Agriculture Imagery
      Program [NAIP] imagery) to classify the lidar data.
    </srccontr>
  </srcinfo>
  <procstep>
    <procdesc>Lidar Pre-Processing: Airborne global positioning system (GPS)
      and inertial measurement unit (IMU) data were merged to develop a Single
      Best Estimate of Trajectory (SBET) of the lidar system 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 were derived. This relative calibration was repeated
      iteratively until residual errors between overlapping swaths, across all
      project lifts, was reduced to 2 cm or less. Data were then block adjusted
      to match surveyed calibration control. Raw data NVA were checked using
      independently surveyed check points. Swath overage points were identified
      and tagged within each swath file.

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    <proccont>
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          <cntper>Manny Puntas</cntper>
        </cntorgp>
        <cntaddr>
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        <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 quality control (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. All classification
    tags are stored in the original swath files. After completion of
    classification and final QC approval, the NVA and vegetated vertical
    accuracy (VVA) for the project are calculated. Sample areas for each
    land cover type present in the project 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>
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      <cntper>Manny Puntas</cntper>
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    <cntvoice>555-555-556</cntvoice>
    <cntfax>555-5550-1236</cntfax>
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    <hours>Monday through Friday 8:00 AM to 4:00 PM (Central Time)
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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.
```

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          </cntinst>
        </cntinfo>
      </proccont>
    </procstep>
  </lineage>
</dataqual>
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  </ptvctinf>
</spdoinfo>
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    <planar>
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        coordinates
      </altenc>
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  </vertdef>
</spref>
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  <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>
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        <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>
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  <metrd> 20101207</metrd>
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    <cntinfo>
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        <cntper>John Smith</cntper>
      </cntorgp>
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        <state>MO</state>
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      <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>Federal Geographic Data Committee (FGDC) Content Standard for
    Digital Geospatial Metadata (CSDGM)
  </metstdn>
```

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    <metac>None</metac>
    <metuc>None</metuc>
    <metsi>
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    </metsi>
    <metextns>
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      <metprof>None</metprof>
    </metextns>
  </metainfo>
</metadata>
```

Appendix 4. Light Detection and Ranging 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 Identifier (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 data
          <!--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
        data, which encompasses a 1,000 meter buffer around Phelps and Dent
        Counties in Missouri, approximately 829 square miles.
        Dataset Description: This dataset consists of 457 lidar data 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 subswath files, each less than
        2GB.
        Ground Conditions: water at normal levels; no unusual inundation; no
        snow; leaf off
        <!--REQUIRED Element: Abstract
          A brief narrative summary of the dataset.
          The Abstract should include a consolidated summary of other
          elements that are included elsewhere in this metadata file, for ease
          of use.
          Domain: free text
        -->
      </abstract>
      <lidar>
```

```
<!-- REQUIRED section: for LAS metadata
  files
-->
<ldrinfo>
  <!--REQUIRED Group:  This group of tags contains metadata about the
    sensor and collection conditions.
  -->
  <ldrspec>EXAMPLE: U.S. Geological Survey (USGS) – National Geospatial
    Program (NGP) Lidar Base Specification v1.3
    <!--REQUIRED Element: the lidar specification applicable to the
      point data
    -->
  </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 Density, in Points Per
      Square Meter
    -->
  </ldrdens>
  <ldranps>EXAMPLE: 0.7071
    <!--REQUIRED Element: the Nominal Pulse Spacing, in Meters -->
   </ldranps>
  <ldradens>EXAMPLE: 2
    <!--REQUIRED Element: the Nominal Pulse Density, in Points Per
      Square Meter
    -->
  </ldradens>
  <ldrfltht>EXAMPLE: 3000
    <!--REQUIRED Element: the nominal flight height Above Mean Terrain
      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 -->
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  <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>
    <ldrgeoid>EXAMPLE: National Geodetic Survey (NGS) Geoid12b
      <!--REQUIRED Element: Geoid used for vertical reference. -->
    </ldrgeoid>
  </ldrinfo>
  <ldraccur>
    <!-- REQUIRED Group: This group of tags contains information on point
      data accuracy. Not all tags within this group data are mandatory. The
      nonvegetated vertical accuracy (NVA) of the raw point data is required.
      A vegetated vertical accuracy (VVA) value for the classified point data
      is optional, but is required to be reported if it is available.
      ALL Values are reported in Meters.
    -->
    <ldrchacc>EXAMPLE: 0.5
      <!--REQUIRED Element: the calculated horizontal accuracy of the point
        data.
        If none specified, enter 0.
      -->
    </ldrchacc>
    <rawnva>EXAMPLE: 0.11
      <!--REQUIRED Element: the calculated NVA of the raw point data.
      -->
    </rawnva>
    <rawnvan>EXAMPLE: 27
      <!--REQUIRED Element: the number of check points used to calculate
        the reported NVA of the raw point data.
      -->
    </rawnvan>
    <clsnva>EXAMPLE: 0.09
      <!--OPTIONAL Element: the calculated NVA of the classified point
        data (required if available).
      -->
    </clsnva>
    <clsnvan>EXAMPLE: 27
      <!--REQUIRED Element: the number of check points used to calculate
        the reported NVA of the classified point data (required if
        available).
```

```
    -->
  </clsnvan>
  <clsvva>EXAMPLE: 0.188
    <!--OPTIONAL Element: the calculated VVA of the classified point
      data (required if available).
    -->
  </clsvva>
  <clsvvan>EXAMPLE: 86
    <!--OPTIONAL Element: the number of check points used to calculate
      the VVA of the classified point data (required if available).
    -->
  </clsvvan>
</ldraccur>
<lasinfo>
  <!-- REQUIRED Group: This group of tags contains information on the
    LAS version and classification values for the point data.
  -->
  <lasver>EXAMPLE: 1.4
    <!-- REQUIRED Element: The version of the LAS Standard applicable to
      this dataset.
    -->
  </lasver>
  <lasprf>EXAMPLE: 6
    <!-- REQUIRED Element: The Point Data Record Format used for the
      point data.
    -->
  </lasprf>
  <laswheld>EXAMPLE: Withheld (ignore) points were identified in these
    files using the standard LAS Withheld bit flag.
    <!-- REQUIRED Element: Describe how withheld points are identified.
    -->
  </laswheld>
  <lasolap>EXAMPLE: Swath “overage” points were identified in these
    files using the standard LAS overlap bit flag.
    <!-- REQUIRED Element: This element describes how overage points are
      identified.
    -->
  </lasolap>
  <lasintr>EXAMPLE: 11
    <!-- REQUIRED Element: This element specifies the native 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: 1</clascode>
      <!-- REQUIRED Element: This element specifies classification code.
        Domain: positive integer between 0 and 255
      -->
    <clasitem>EXAMPLE: Undetermined/Unclassified</clasitem>
      <!-- REQUIRED Element: This element describes the object
        identified by the classification code; the type of object from
        which the lidar point was reflected, or the status of the
        classification of point.
        Domain: free text
      -->
  </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: Low noise</clasitem>
    </lasclass>
    <lasclass>
      <clascode>EXAMPLE: 9</clascode>
      <clasitem>EXAMPLE: Water</clasitem>
    </lasclass>
    <lasclass>
      <clascode>EXAMPLE: 17</clascode>
      <clasitem>EXAMPLE: Bridges</clasitem>
    </lasclass>
    <lasclass>
      <clascode>EXAMPLE: 18</clascode>
      <clasitem>EXAMPLE: High Noise</clasitem>
    </lasclass>
    <lasclass>
      <clascode>EXAMPLE: 20</clascode>
      <clasitem>EXAMPLE: Ignored ground</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 the Federal Emergency Management Agency (FEMA)
  for flood-plain mapping. These raw lidar data were used to
  create classified lidar LAS files, intensity images, 3D breaklines, and
  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 date is the date of the lidar collection, if the collection
            was completed in one day.
            The field MUST be formatted YYYYMMDD
          -->
        </caldate>
      </sngdate>
      <mdattim>
        <!-- Begin example of a multiple dates -->
        <sngdate>
          <caldate> 20100216
            <!--REQUIRED Element: Calendar Date
              This date 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 date 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 date is the beginning date of lidar collection.
            The field MUST be formatted YYYYMMDD
          -->
        </begdate>
        <enddate> 20100218
          <!--REQUIRED Element: Ending Date
            This date is the ending date of lidar collection.
            The field MUST be formatted YYYYMMDD
          -->
        </enddate>
      </rngdates>
    </timeinfo>
    <current> EXAMPLE: ground condition
```

```
    <!--REQUIRED Element: Currentness 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 coordinate of the western-most limit of coverage
        of the dataset expressed as longitude. This value will be negative
        in the United States, except for the extreme western Aleutian
        Islands.
        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 coordinate of 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 coordinate of 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 coordinate of 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: The coordinate of the western-most limit of
          coverage of the dataset expressed in the Coordinate Reference
          System in which the data are delivered.
        -->
      </leftbc>
      <rightbc> 664800
        <!--REQUIRED Element: The coordinate of the eastern-most limit of
          coverage of the dataset expressed in the Coordinate Reference
          System in which the data are delivered.
        -->
      </rightbc>
      <topbc> 4225400
        <!--REQUIRED Element: The coordinate of the northern-most limit of
          coverage of the dataset expressed in the Coordinate Reference
          System in which the data are delivered.
        -->
      </topbc>
      <bottombc> 4141400
        <!--REQUIRED Element: The coordinate of the southern-most 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 transpired 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 the limitations of the data.  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:
          The 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 dataset environment
      Description of the dataset in the producer’s processing
      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. No void areas or
    missing data exist.  The raw point data is of good quality and data
    passes NVA 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 nonvegetated
        vertical accuracy (NVA) can be computed for raw lidar data
        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 data.
        The survey check points were distributed throughout the project.
        Specifications for this project require that the NVA 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
          level
          <!--REQUIRED Element: Vertical Positional Accuracy Value
            Vertical accuracy expressed in (ground) meters.
            Clearly state whether this value is root mean square error vertical
            (RMSEz) or AccuracyZ.
            Domain: free text
          -->
        </vertaccv>
        <vertacce> The NVA was tested using 25 independent surveys located in
          open terrain  The survey check points were distributed throughout
          the project. The 25 independent check points were surveyed using the
          closed level loop 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 RMSEz was
          computed to be 0.097 meters. AccuracyZ has been tested to meet
          19.0 cm NVA at 95-percent confidence level using RMSEz x 1.9600 as
          defined by the National Standards for Spatial Data Accuracy (NSSDA);
          assessed and reported using American Society of Photogrammetry and
          Remote Sensing (ASPRS) 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 to making this unclassified LAS swath dataset,
        including, but not limited to, 1) ground control used for calibrating
        the lidar data, 2) the actual lidar acquisition data, and 3)
        independent ground control used to assess the accuracy of the lidar
        point data.
      -->
      <srccite>
        <citeinfo>
          <origin> EXAMPLE: Jiffy Survey, Inc.
```

```
  <!--REQUIRED Element:  Originator
    This element is 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 dataset.
    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 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 unified resource locator (URL) of an online
        computer resource that contains the dataset.
        Domain: free text
      -->
    </onlink>
  </citeinfo>
</srccite>
 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 date is the date of the first source dataset was created.
          The field MUST be formatted YYYYMMDD
        -->
      </caldate>
    </sngdate>
  </timeinfo>
  <srccurr> EXAMPLE: ground condition
    <!--REQUIRED Element: 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>
<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 IDENTIFIER (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 data.
  <!--REQUIRED Element: Source Contribution
    Brief statement identifying the information contributed.
    Domain: free text
  -->
</srccontr>
```

```
</srcinfo>
<srcinfo>
  <srccite>
    <citeinfo>
      <origin>USDA</origin>
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      </title>
      <geoform>raster orthoimagery</geoform>
      <pubinfo>
        <pubplace>USGS EROS</pubplace>
        <publish>USGS EROS</publish>
      </pubinfo>
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      <onlink></onlink>
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  </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 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>
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  <srcscale>50</srcscale>
  <typesrc>online</typesrc>
  <srctime>
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  <rngdates>
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    <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 data.
    </srccontr>
  </srcinfo>
  <procstep>
    <procdesc> EXAMPLE: Lidar Pre-Processing: Airborne GPS and IMU data were
      merged to develop a Single Best Estimate of trajectory (SBET) of the
      lidar system 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 process was repeated
      iteratively until residual errors between overlapping swaths, across
      all project lifts, was reduced to 2 cm or less. Data were then block
      adjusted to match surveyed calibration control. Raw data NVA were
      checked using independently surveyed check points. Swath overage
      points were identified and tagged within each swath file.
      <!--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>
          <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. All classification tags are stored in the original
    swath files. After completion of classification and final QC approval,
    the NVA and VVA for the project are calculated. Sample areas for each
    land cover  type present in the project 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>
      <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 locate
          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”
        -->
      </sdtstype>
      <ptvctcnt> EXAMPLE: 764,567,423
        <!--OPTIONAL Element: Point and Vector Count
          Enter the total number of the point or vector object types 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”
          -->
        </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 is frequently
          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 is frequently
          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 documented
        in Department of Commerce, 1986, Representation of geographic
        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 documented in Department of Commerce,
        1989 (January), State Plane Coordinate System of 1983 (National
        Oceanic and Atmospheric Administration Manual NOS NGS 5): Silver
        Spring MD, National Oceanic and Atmospheric Administration,
        National Ocean Service, Coast and Geodetic Survey.
      -->
    </spcszone>
    <lambertc>
      <stdparll>
        <!--Enter line of constant latitude at which the surface of the
          Earth and the plane of projection 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 is frequently
        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 is frequently
        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 is frequently
        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 is frequently
        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 is frequently
```

```
          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 is frequently
          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 is frequently
          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>EXAMPLE: coordinate pair
    <!-- REQUIRED Element: Planar Coordinate Encoding Method - the means
      used to represent horizontal positions.
      Domain: "coordinate pair" "distance and bearing" "row and column"
      free text
    -->
  </plance>
  <coordrep>
    <absres>0.01
      <!-- REQUIRED Element: Horizontal Resolution in X: The minimum
        distance possible between two adjacent horizontal values in the
        X direction in the horizontal Distance Units of measure.
        Domain: Abscissa Resolution > 0.0
      -->
    </absres>
    <ordres> EXAMPLE: 0.01
      <!-- REQUIRED Element: Horizontal Resolution in Y: The minimum
        distance possible between two adjacent horizontal values in the
        Y direction in the horizontal Distance Units of measure.
        Domain: Ordinate Resolution > 0.0
      -->
```

```
        </ordres>
      </coordrep>
      <plandu>EXAMPLE: meters
        <!--REQUIRED Element: Units in which altitudes are recorded.
          Domain: "meters" "U.S. feet" "Intl. feet" free text
        -->
      </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 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.
      This section 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 that 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: Federal Geographic Data Committee (FGDC) Content Standard
```

```
  for Digital Geospatial Metadata (CSDGM)
  <!--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 Version. 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 that 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 the dataset.
        -->
      </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>
```

Appendix 5. Well-Known Text Coordinate Reference System Examples

Open Geographic Consortium (OGC) Well-known Text (WKT) example with compound coordinate system

{NAD83(2011) + NAVD88 height (meters)}

Command string: **`$ gdalsrsinfo -o wkt “EPSG:6427+5703”`**

Output:

```
COMPD_CS[“NAD83(2011) / Colorado Central + NAVD88 height - Geoid12b”,
  PROJCS[“NAD83(2011) / Colorado Central”,
    GEOGCS[“NAD83(2011)”,
      DATUM[“NAD83 National Spatial Reference System 2011”,
        SPHEROID[“GRS 1980”,6378137,298.257222101,
          AUTHORITY[“EPSG”,”7019”]],
        AUTHORITY[“EPSG”,”1116”]],
        PRIMEM[“Greenwich”,0,
          AUTHORITY[“EPSG”,”8901”]],
        UNIT[“degree”,0.0174532925199433,
          AUTHORITY[“EPSG”,”9122”]],
      AUTHORITY[“EPSG”,”6318”]],
    PROJECTION[“Lambert_Conformal_Conic_2SP”],
      PARAMETER[“standard_parallel_1”,39.75],
      PARAMETER[“standard_parallel_2”,38.45],
      PARAMETER[“latitude_of_origin”,37.83333333333334],
      PARAMETER[“central_meridian”,-105.5],
      PARAMETER[“false_easting”,914401.8289],
      PARAMETER[“false_northing”,304800.6096],
    UNIT[“meter”,1,
      AUTHORITY[“EPSG”,”9001”]],
    AXIS[“X”,EAST],
    AXIS[“Y”,NORTH],
    AUTHORITY[“EPSG”,”6427”]],
  VERT_CS[“NAVD88 height - Geoid12b”,
    VERT_DATUM[“North American Vertical Datum 1988”,
      AUTHORITY[“EPSG”,”5103”]],
    UNIT[“meter”,1,
      AUTHORITY[“EPSG”,”9001”]],
    AXIS[“Up”,UP],
    AUTHORITY[“EPSG”,”5703”]]]
```

OGC WKT example with compound coordinate system {NAD83(2011) + NAVD88 height (ftUS)}

Command string: **`$ gdalsrsinfo -o wkt "EPSG:6434+6360"`**

Output:

```
COMPD_CS["NAD83(2011) / Connecticut (ftUS) + NAVD88 height (ftUS) - Geoid12b",
  PROJCS["NAD83(2011) / Connecticut (ftUS)",
    GEOGCS["NAD83(2011)",
      DATUM["NAD83 National Spatial Reference System 2011",
        SPHEROID["GRS 1980",6378137,298.257222101,
          AUTHORITY["EPSG","7019"]],
        AUTHORITY["EPSG","1116"]],
        PRIMEM["Greenwich",0,
          AUTHORITY["EPSG","8901"]],
        UNIT["degree",0.0174532925199433,
          AUTHORITY["EPSG","9122"]],
        AUTHORITY["EPSG","6318"]],
      PROJECTION["Lambert_Conformal_Conic_2SP"],
        PARAMETER["standard_parallel_1",41.86666666666667],
        PARAMETER["standard_parallel_2",41.2],
        PARAMETER["latitude_of_origin",40.83333333333334],
        PARAMETER["central_meridian",-72.75],
        PARAMETER["false_easting",1000000],
        PARAMETER["false_northing",500000],
      UNIT["US survey foot",0.3048006096012192,
        AUTHORITY["EPSG","9003"]],
      AXIS["X",EAST],
      AXIS["Y",NORTH],
      AUTHORITY["EPSG","6434"]],
   VERT_CS["NAVD88 height (ftUS) - Geoid12b",
     VERT_DATUM["North American Vertical Datum 1988",2005,
       AUTHORITY["EPSG","5103"]],
     UNIT["US survey foot",0.3048006096012192,
       AUTHORITY["EPSG","9003"]],
     AXIS["Up",UP],
     AUTHORITY["EPSG","6360"]]
```

Appendix 6. Supplemental Information

Federal Geographic Data Committee Content Standard for Digital Geospatial Metadata:
https://www.fgdc.gov/metadata/csdgm/

International Standards Organization 19115-1:2014 Geographic Information – Metadata:
https://www.iso.org/obp/ui/#iso:std:iso:19115:-1:ed-1:v1:en:en/

Metadata Parser:
https://geology.usgs.gov/tools/metadata

National Geodetic Survey, Geoid and Deflection Models:
https://www.ngs.noaa.gov/GEOID/models.shtml

National Geodetic Survey, National Adjustment of 2011 Project:
https://www.ngs.noaa.gov/web/surveys/NA2011/

U.S. Geological Survey (USGS) 3-dimensional Elevation Program (3DEP) website:
https://nationalmap.gov/3DEP

For more information about this publication, contact
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Sioux Falls, SD 57198
(605) 594–6151

For additional information visit https://eros.usgs.gov

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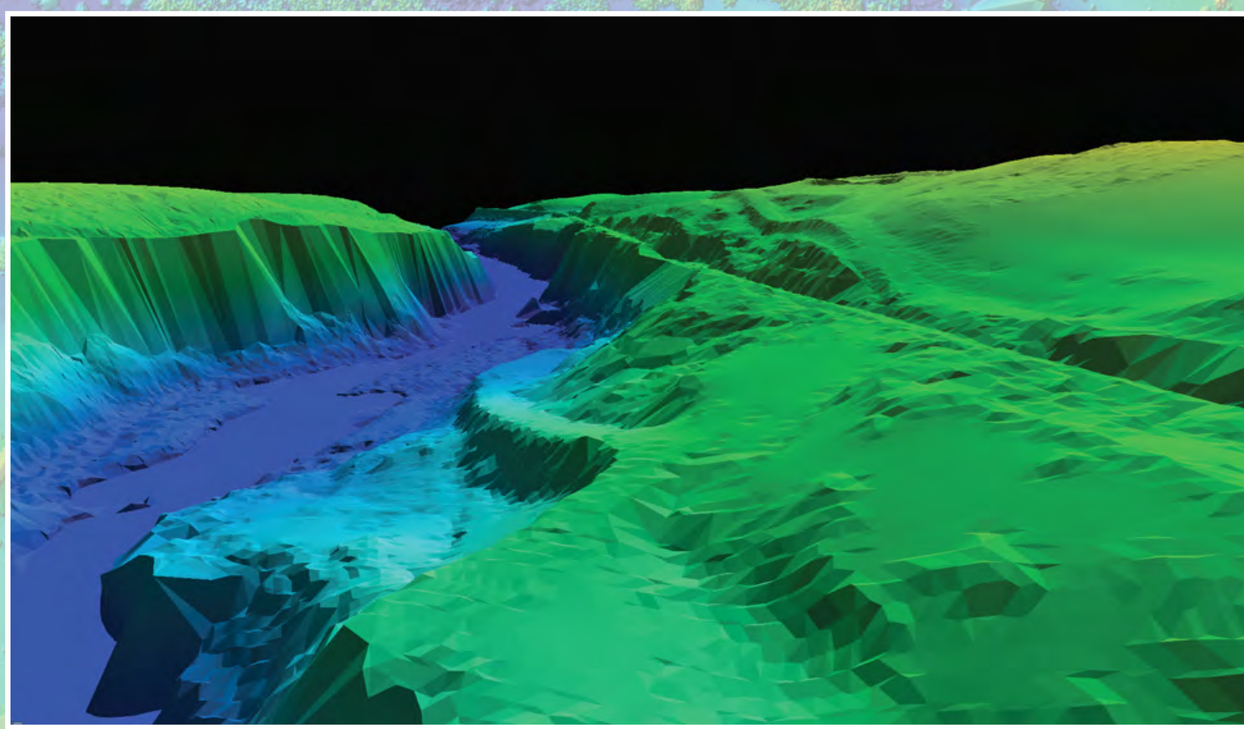

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