State of Kentucky
LiDAR and Imagery Procurement Group
Technical Committee

LiDAR Production
Technical Specifications

Latest Update: June 13, 2016

I. PROJECT AREA

The total ***Project Area*** includes the entirety of the state of Kentucky, subdivided into two project sub-areas. The "***Base Accuracy***" project sub-area is defined as the **project region(s)** for which the imagery collection will be carried out adhering to the base specifications. The "***Higher Accuracy"*** project sub-area will be defined as **project region(s)** encompassing cities, counties, regional groupings or other administrative jurisdictions subscribing to the buy-up options for acquiring LiDAR (see section VII below).

These base specifications define minimum parameters, and it is expected that local conditions in any given project area, specialized applications for the data, or the preferences of cooperators, may mandate more stringent requirements. The collection of more detailed, accurate, or value-added data is encouraged for the buy-up options. A list of common options beyond the base specification is provided in Section VII.

II. COLLECTION

1. Multiple Discrete Return, capable of at least 3 returns per pulse

   Note: Full waveform collection is both acceptable and encouraged; however, waveform data is regarded as supplemental information. The requirement for deriving and delivering multiple discrete returns remains in force in all cases.

2. Intensity values for each return.
3. Nominal Pulse Spacing (NPS) no greater than 1 meters; assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.
4. Collections designed to achieve the NPS through swath overlap or multiple passes are generally discouraged. Such collections may be permitted in special cases, with prior approval.
5. Data Voids [areas => $(4*NPS)^2$, measured using 1st-returns only] within a single swath are not acceptable, except:
   - where caused by water bodies
   - where caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing.

- where appropriately filled-in by another swath

6. The spatial distribution of geometrically usable points is expected to be uniform and free from clustering. In order to ensure uniform densities throughout the data set:
    - A regular grid, with cell size equal to the design NPS will be laid over the data.
    - At least 90% of the cells in the grid shall contain at least 1 LiDAR point.
    - Clustering will be tested against the 1st return only data
    - Acceptable data voids identified previously in this specification are excluded.

    Note: This requirement may be relaxed in areas of significant relief where it is impractical to maintain a consistent NPS.

7. Preferred Scan Angle (Total FOV) should not exceed 40°. Quality assurance on collections performed using wider scan angles will be particularly rigorous in the edge-of-swath areas. Horizontal and vertical accuracy shall remain within the requirements as specified below.
8. Vertical Accuracy:

    *Note: The term "accuracy" has commonly been used in the industry to refer to the tested $RMSE_Z$ of the LiDAR data. Technically, this is improper usage: NSSDA Accuracy is defined as: the 95% confidence level, equal to ($RMSE_Z$*1.96) in a set of errors assumed to be normally distributed. In keeping with common usage to reduce confusion, this Specification's use of the term "accuracy" is indicative of the RMSE value and will be annotated as such. See the FEMA "Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A", Section A.3.2 for additional information.*

    NSSDA $RMSE_Z$ = 15 cm (NSSDA $Accuracy_Z$ 95% = 30 cm) or better; assessment procedures to comply with FEMA guidelines.

    Note: This requirement may be relaxed to NSSDA $RMSE_Z$ = 18.5 cm (NSSDA $Accuracy_Z$ 95% = 37 cm) in cases:

    - *where there exists a demonstrable increase in cost to obtain 15 cm $RMSE_Z$ accuracy over 18.5 cm $RMSE_Z$ accuracy.*
    - *where the 18.5 cm $RMSE_Z$ specification is needed to conform to previously contracted phases of a single larger overall collection effort, i.e., multi-year statewide collections, etc.*
    - *where the Technical Group agrees that it is reasonable and in the best interest of all stakeholders to use the 18.5 cm $RMSE_Z$ specification.*

9. Relative accuracy of 5 cm $RMSE_Z$ or better; assessment to be made swath-to-swath and within single swaths.

    Note: This requirement will be relaxed to 6 cm $RMSE_Z$ on collections using the 18.5 cm $RMSE_Z$ overall specification.

10. Flight line overlap 20% or greater, as required to ensure there are no data gaps between the usable portions of the swaths. Collections in high relief terrain are expected to require greater overlap. Any data with gaps between the geometrically usable portions of the swaths will be rejected.
    - Collection Area: The defined Project Region(s) within Project sub-areas, buffered by a minimum of 200*NPS.
11. Collection Conditions:
    - Atmospheric: Cloud and fog-free between the aircraft and ground
    - Ground:
        - Snow free; very light, undrifted snow may be acceptable in special cases, with prior approval.
    - No unusual flooding or inundation, except in cases where the goal of the collection is to map the inundation.
    - Vegetation: Three consecutive leaf-off seasons in the 2011-2013 triennium.
        - As numerous factors will affect vegetative condition at the time of any collection, the main requirement is that penetration to the ground must be adequate to produce an accurate and reliable bare-earth surface suitable for incorporation into the 1/9 arc-second (3-meter) NED.
        - Collections for specific scientific research projects may be exempted from this requirement, with prior approval.

III. DATA PROCESSING and HANDLING

1. All processing should be carried out with the understanding that all point deliverables are required to be in fully compliant LAS format v1.4. Data producers are encouraged to review the LAS specification in detail.
2. If full waveform data is collected, delivery of the waveform packets is required.
   LAS v1.4 deliverables with waveform data are to use external “auxiliary” files with the extension “.wdp” for the storage of waveform packet data. See the LAS v1.4 Specification for additional information.
   GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each return. Adjusted GPS Time is defined to be Standard (or satellite) GPS time minus 1*109. See the LAS Specification for more detail.
3. All mapping products will be delivered in Kentucky Single Zone State Plane coordinates (parameters defined in FIPS 1600, and units of U.S. Survey Feet), NAD83* geometric datum (NSRS2007 or CORS96 adjustment), and NAVD88 vertical datum. GPS derived NAVD88 heights will use the Geoid09* model. [* Use most current adjustment and geoid model available from the National Geodetic Survey at time of data processing]
4. Long swaths (those which result in a LAS file larger than 2GB) should be split into segments. Each segment will thenceforth be regarded as a unique swath. Other swath segmentation criteria may be acceptable, with prior approval.
5. Point Families (multiple return “children” of a single “parent” pulse) shall be maintained intact through all processing prior to tiling. Multiple returns from a given pulse shall be stored in sequential order.

6. Each swath will be assigned a unique File Source ID. The Point Source ID field shall be set equal to the File Source ID prior to any processing of the data. See the LAS Specification.
7. All collected swaths are to be delivered. This includes calibration swaths and cross-ties. All collected points are to be delivered. No points are to be deleted from the swath LAS files. This in no way requires or implies that calibration swath data are to be included in product generation. Excepted from this are extraneous data (aircraft turns, transit between the collection area and airport, transit between fill-in areas, etc.) that may be permanently removed.
8. Within each LAS file, points from a given swath shall be stored together and in their collected order.
9. Outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath, and other points deemed unusable are to be identified using the "Withheld" flag, as defined in the LAS specification.
    - This applies primarily to points which are identified during pre-processing or through automated post-processing routines.
    - "Noise points" identified during manual Classification and Quality Assurance/Quality Control (QA/QC) may be assigned the standard LAS classification value (class value = 7), regardless of whether the noise is "low or "high" relative to the ground surface.
10. The Overlap Classification (class value = 12) shall not be used. ALL points not tagged as "Withheld" are to be classified.
11. If overlap points are required to be differentiated for processing, they are to be tagged using Bit:0 of the User Data byte, as defined in the LAS specification. (SET=Overlap). If so required, this tag is to be included in the delivered point data.
12. Positional Accuracy Validation: The absolute and relative accuracy of the data, both horizontal and vertical, relative to known control, shall be verified prior to classification and subsequent product development. A detailed report of this validation is a required deliverable.
13. Classification Accuracy: It is expected that due diligence in the classification process will produce data that meets the following test:

    Within any 1km x 1km area, no more than 2% of points will possess a demonstrably erroneous classification value. This includes points in Classes 0 and 1 that should correctly be included in a different Class required by the contract.

    Note: This requirement may be relaxed to accommodate collections in areas where the Technical Group agrees classification to be difficult.

14. Tiles:

    Note: This section assumes a projected coordinate reference system.

    - Tiling scheme: the elevation data derived shall be divided into smaller non-overlapping areas or tiles. The tiling scheme for indexing the project area and project regions will be based on the 10K or 5K US Survey Feet (SPCS) tiling scheme grid used in previous tiling efforts in Kentucky. The tile extent and grid shall be approved per project area.
    - Tile size must be an integer multiple of the cell size of raster deliverables.

- Tiled deliverables shall conform to the tiling scheme, without added overlap.
- Tiled deliverables shall edge-match seamlessly in both the horizontal and vertical.

IV. HYDRO-FLATTENING REQUIREMENTS

Note: Please refer to Section VI for reference information on hydro-flattening.

1. Inland Ponds and Lakes:

   - ~1-acre or greater surface area (~250' diameter for a round pond)
   - Flat and level water bodies (single elevation for every bank vertex defining a given water body).
   - The entire water surface edge must be at or just below the immediately surrounding terrain.
   - Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, should be treated as rivers.

2. Inland Streams and Rivers:

   - 100' **nominal** width: This should not unnecessarily break a stream or river into multiple segments. At times it may squeeze slightly below 100' for short segments. Data producers should use their best professional judgment.
   - Flat and level bank-to-bank (perpendicular to the apparent flow centerline); gradient to follow the immediately surrounding terrain.
   - The entire water surface edge must be at or just below the immediately surrounding terrain.
   - Streams should break at road crossings (culvert locations). These road fills should not be removed from DEM. However, streams and rivers should **not** break at bridges. Bridges should be removed from DEM. When the identification of a feature as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.

3. Non-Tidal Boundary Waters:

   - Represented only as an edge or edges within the project area; collection does not include the opposing shore.
   - The entire water surface edge must be at or below the immediately surrounding terrain.
   - The elevation along the edge or edges should behave consistently throughout the project. May be a single elevation (i.e., lake) or gradient (i.e., river), as appropriate.

4. Collection and integration of single-line streams within this LiDAR project is encouraged. While the collection and integration of these breaklines are not requirements, if these are used and incorporated into the USGS DEMs the following guidelines should be met:

1. All vertices along single-line stream breaklines are at or below the immediately surrounding terrain.
2. Single-line stream breaklines are not to be used to introduce cuts into the DEM at road crossings (culverts), dams, or other such features. This is hydro-enforcement and as discussed in Section VI, creates a non-traditional DEM that is not suitable for integration into the NED.

3. All breaklines used to modify the surface are to be delivered to the Kentucky Division of Geographic Information with the DEMs.

With respect to the process or methodology to be used for breakline collection, extraction, or integration, the following general guidelines must be adhered to:

1. Bare-earth LiDAR points that are in close proximity to breaklines should be excluded from the DEM generation process. This is analogous to the removal of mass points for the same reason in a traditional photogrammetrically compiled DTM. The proximity threshold for reclassification as “Ignored Ground” is at the discretion of the data producer, but in general should be approximately equal to the NPS.

2. These points are to be retained in the delivered LiDAR point dataset and shall be reclassified as “Ignored Ground” (class value = 10) so that they may be subsequently identified.

3. Delivered data must be sufficient to effectively recreate the delivered DEMs using the LiDAR points and breaklines without significant further editing.

V. DELIVERABLES

The Kentucky Division of Geographic Information and the Commonwealth shall have unrestricted rights to all delivered data and reports, which will be placed in the public domain. This specification places no restrictions on the data provider's rights to resell data or derivative products as they see fit.

1. Metadata

- Collection Report detailing mission planning and flight logs.
- Survey Report detailing the collection of control and reference points used for calibration and QA/QC.
- Processing Report detailing calibration, classification, and product generation procedures including methodology used for breakline collection and hydro-flattening *(see Section VI for more information on hydro-flattening)*.
- QA/QC Reports (detailing the analysis, accuracy assessment and validation of:
    - The point data (absolute, within swath, and between swath)
    - The bare-earth surface (absolute)
    - Other optional deliverables as appropriate
- Control and Calibration points: All control and reference points used to calibrate, control, process, and validate the LiDAR point data or any derivative products are to be delivered.

- Geo-referenced, digital spatial representation of the precise extents of each delivered dataset. This should reflect the extents of the actual LiDAR source or derived product data, exclusive of Triangular Irregular Network (TIN) artifacts or raster NODATA areas. A union of tile boundaries or minimum bounding rectangle is not acceptable. ESRI polygon feature class in a file geodatabase for loading into ArcGIS is preferred.
- Product metadata (FGDC compliant, XML format metadata). One file for each:
  - Project
  - Lift
  - Tiled deliverable product group (classified point data, bare-earth DEMs, breaklines, etc.).

Metadata files for individual tiles are not required.

2. Classified Point Cloud

Note: Delivery of a classified point cloud is a standard requirement.

- Fully compliant LAS v1.4, Point Record Format 1, 3, 4, or 5
- LAS v1.4 deliverables with waveform data are to use external “auxiliary” files with the extension “.wdp” for the storage of waveform packet data. See the LAS v1.4 Specification for additional information.
- Georeference information included in LAS header
- GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each return.
- Intensity values (rescaled to 8-bit)
- Tiled delivery, without overlap
- Classification Scheme (minimum):

Code Description
1 Processed, but unclassified
2 Bare-earth or ground
7 Noise (low or high, manually identified, if needed)
9 Water
10 Ignored Ground (Breakline Proximity)

Note: Class 7, Noise, is included as a convenience for the data producer. It is not required that all “noise” be assigned to Class 7.

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

3. Bare Earth Surface (Raster DEM)

Note: Delivery of a bare-earth DEM is a standard requirement.

- Cell Size no greater than 3 meters or 10 feet, and no less than the design

- Nominal Pulse Spacing (NPS).
- Delivery in an industry-standard, GIS-compatible, 32-bit floating point raster format (ERDAS .IMG preferred)
- Georeference information shall be included in raster file
- Tiled delivery, without overlap
- DEM tiles will show no edge artifacts or mismatch
- No tiles with void (i.e. “NODATA”) areas will be accepted
- Vertical Accuracy ($RMSE_Z$) of the bare earth surface is to be assessed using the methods described in the FEMA “Guidelines and Specifications for Flood
- Hazard Mapping Partners, Appendix A”, Section A.8.5 paragraph 1, Section A.8.6.1, and Section A.8.6.2 (substituting the contracted vertical accuracy requirements ($RMSE_Z$) for those listed in the FEMA document). All QA/QC analysis materials and results are to be delivered.
- Depressions (sinks), natural or man-made, are not to be filled (as in hydro-conditioning and hydro-enforcement).
- Water Bodies (ponds and lakes), wide streams and rivers (“double-line”), and other non-tidal water bodies as defined in Section III are to be hydro-flattened within the DEM. Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are larger than ~1 acre in area (equivalent to a round pond ~250’ in diameter), to all streams that are nominally wider than 100’, and to all non-tidal boundary waters bordering the project area regardless of size. The methodology used for hydro-flattening is at the discretion of the data producer.

Note: Please refer to the Sections III and VI for detailed discussions of hydro-flattening.

4. Breaklines

Note: Delivery of the breaklines used in hydro-flattening is a standard requirement. If hydro-flattening is achieved through other means, this section may not apply.

1. All breaklines developed for use in hydro-flattening shall be delivered as an ESRI feature class (PolylineZ or PolygonZ format, as appropriate to the type of feature represented and the methodology used by the data producer).
2. Feature class in a file geodatabase for loading into ArcGIS is preferred.
3. Each feature class will include properly formatted and accurate georeference information in the standard location
4. Breakline elevations will use the same coordinate reference system (horizontal and vertical) and units as the LiDAR point delivery.
5. Breakline delivery may be as a continuous layer or in tiles, at the discretion of the data producer. Tiled deliveries must edge-match seamlessly in both the horizontal and vertical.

6. Ground Control Points

The plotted position of each control point shall lie to an accuracy of one-hundredth (1/100) of an inch of its true position, as expressed by the State Plane coordinate for that point. Control point coordinates will be submitted as a dataset.

The density of GCP will be *no less* than twenty (20) GCPs per type of major land cover class.

The complete set of KGRN (formerly known as HARN) points in Kentucky will be used, as dictated by availability.

GCP preference should be given to panel points associated to permanent structures, recoverable so as to be used in future survey work. Examples are manholes, curbs, utilities structures, etc.

VI. COMMON BUY-UP OPTIONS

1. Completion of remaining, unscheduled portion of administrative unit (county, incorporated city, etc.)
2. Independent 3rd-Party QA/QC by another sub-contractor
3. Increased NPS: < 1.0 m
4. Increased Vertical Accuracy ($RMSE_Z$)
   - 12 cm, 9.25 cm, etc…
5. Additional Environmental Constraints
   - Tidal coordination, flood stages, crop/plant growth cycles, etc.
   - Shorelines corrected for tidal variations within a collection
6. Top-of Canopy (First-Return) Raster Surface (tiled). Raster of the highest return on each cell is preferred.
7. Intensity Images (8-bit gray scale, tiled)
8. Detailed Classification (additional classes):

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

9. Breaklines (PolylineZ and PolygonZ) for single-line hydrographic features (narrow streams not collected as double-line), including appropriate integration into delivered DEMs
10. Breaklines (PolylineZ and PolygonZ) for other features (TBD), including appropriate integration into delivered DEMs
11. Extracted Buildings (PolygonZ): Footprints with maximum elevation and/or height above ground as an attribute.
12. Other products as defined by requirements and agreed upon in advance of funding commitment.

VII. HYDRO-FLATTENING REFERENCE

The subject of modifications to LiDAR-based DEMs is somewhat new, and although authoritative references are available, there remains significant variation in the understanding of the topic across the industry. The following material was developed to provide a definitive reference on the subject only as it relates to the creation of DEMs intended to be integrated into the USGS NED. The information presented here is not meant to supplant other reference materials and it should not be considered authoritative beyond its intended scope.

The term "**hydro-flattening**" – a new term - of DEMs is predominantly accomplished through the use of breaklines, and this method is considered standard. Although other techniques may exist to achieve similar results, this section assumes the use of breaklines. These specifications do not require any specific method to accomplish this.

The "Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition" (Maune *et al.,* 2007) provides the following definitions related to the adjustment of DEM surfaces for hydrologic analyses:

1. **Hydrologically-Conditioned (Hydro-Conditioned)**

Processing of a DEM or TIN and so that the flow of water is continuous across the entire terrain surface, including the removal of all spurious sinks or pits. The only sinks that are retained are the real ones on the landscape. Whereas "hydrologically-enforced" is relevant to drainage features that are generally mapped, "hydrologically-conditioned" is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether that flow is in a stream channel or not. The purpose for continuous flow is so that relationships/links among basins/catchments can be known for large areas. This term is specifically used when describing EDNA (see Chapter 4), the dataset of NED derivatives made specifically for hydrologic modeling purposes.

2. **Hydrologically-Enforced (Hydro-Enforced)**

Processing of mapped water bodies so that lakes and reservoirs are level and so that streams flow downhill. For example, a DEM, TIN or topographic contour dataset with elevations removed from the tops of selected drainage structures (bridges and culverts) so as to depict the terrain under those structures.

Hydro-enforcement enables hydrologic and hydraulic models to depict water flowing under these structures, rather than appearing in the computer model to be dammed by them because of road deck elevations higher than the water levels. Hydro-enforced TINs also utilize breaklines along shorelines and stream centerlines, for example, where these breaklines form the edges of TIN triangles along the alignment of drainage features.

Shore breaklines for streams would be 3-D breaklines with elevations that decrease as the stream flows downstream; however, shore breaklines for lakes or reservoirs would have the same elevation for the entire shoreline if the water surface is known or assumed to be level throughout. See also the definition for "hydrologically-conditioned" which has a slightly different meaning.

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

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

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

For years, raster Digital Elevation Models (DEMs), have been created from a Digital Surface Model (DSM) of mass-points and breaklines, which in turn were created through photogrammetric compilation from stereo imagery. Photogrammetric DSMs inherently contain breaklines defining the edges of water bodies, coastlines, single line streams, and double-line streams and rivers, as well as numerous other surface features.

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

In order to maintain the consistent character of the NED as a traditional DEM, all DEMs delivered will have their inland water bodies flattened.

This does not imply that a complete network of topologically correct hydrologic breaklines be developed for every dataset; only those breaklines necessary to ensure that the conditions defined in Section III exist in the final DEM.

VIII. REFERENCES:

- American Society for Photogrammetry and Remote Sensing, 2011. LAS Specification. Version 1.4-R13. 15 July 2013. http://www.asprs.org/wp-content/uploads/2010/12/LAS_1_4_r13.pdf (Accessed: 01 May 2016)
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- USGS NED Website: http://ned.usgs.gov (Accessed: 01 May 2016)
- USGS CLICK Website: https://lta.cr.usgs.gov/lidar_digitalelevation (Accessed: 01 May 2016)
- RFP-10-89 Indiana 2010 Orthophotography Program Section One. General Information and Requested Products/Services. 2010. http://www.igic.org/projects/orthos2010/rfp-10-89.pdf (Accessed: 01 May 2016)