STATE OF KENTUCKY
LIDAR PRODUCTION
TECHNICAL SPECIFICATIONS

LATEST UPDATE: **APRIL 22, 2017**

I. PROJECT AREA, SUB-AREAS, AND REGIONS

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 LiDAR collection will be carried out adhering to the base specifications (see Section II.3 below). The "***Higher Accuracy"*** project sub-area will be defined as potentially multiple **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 region, 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

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.

1. Multiple Discrete Return, capable of at least 3 returns per pulse
2. Intensity values for each return at 16-bit resolution
3. Nominal Pulse Spacing (NPS) no greater than **0.7 meters as defined for Quality Level 2 (QL2),** according to the USGS LiDAR Base Specification: http://dx.doi.org/10.3133/tm11B4**).** Assessment and reporting of the NPS is made against single swath, single instrument, first return only data, including only the geometrically usable part of the swath (typically the center 95 percent) and excluding acceptable data voids.
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:
   a. where caused by water bodies

b. where caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing.

c. where appropriately filled-in by another swath

6. The spatial distribution of geometrically usable points will be uniform and regular. Although LiDAR instruments do not produce regularly gridded points, collections shall be planned and executed to produce an aggregate first return point cloud that approaches a regular lattice of points, rather than a collection of widely spaced, high-density profiles of the terrain. The regularity of the point pattern and density throughout the dataset is important and will be assessed by using the following steps:

   a. Generating a density grid from the data with cell sizes equal to twice the design aggregate NPS (ANPS) and a radius equal to the design ANPS.

   b. Ensuring at least 90 percent of the cells in the grid contain at least one LiDAR point.

   c. Using individual (single) swaths, with only the first return points located within the geometrically usable center part (typically 95 percent) of each swath.

   d. Excluding acceptable data voids previously identified in this specification.

   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 or ANPS.

   Note: KYAPED may allow for lower passing thresholds for this requirement in areas of substantial relief where maintaining a regular and uniform point distribution is impractical.

7. Preferred Scan Angle (Total Field of View) should not exceed 40°. Quality assurance on collections performed using wide 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: strict adherence is expected to the requirements for absolute and relative vertical accuracy, for LiDAR data and derived DEMs corresponding to the **QL2** category as stipulated in the USGS LiDAR Base Specification (page 10, tables 4 and 5; http://dx.doi.org/10.3133/tm11B4). For example in the case of **QL2** absolute vertical accuracy requirements: for non-vegetated areas (NV) RMSEz ≤10.0 cm, while NV vertical accuracy (95% confidence level): ≤19.6 cm; and for vegetated areas (V) 95% confidence level vertical accuracy ≤29.4 cm.

9. 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.

10. Defined Project Region (DPR): The defined Project Region(s) within Project sub-areas
11. Buffered Project Region (BPR): the DPR, buffered by a minimum of 200*NPS.
12. Conditions for collection of LiDAR data will follow these guidelines:
    a. Atmospheric conditions shall be cloud and fog free between the aircraft and ground during all collection operations.
    b. Ground conditions shall be snow free. Very light, undrifted snow may be acceptable in special cases, with prior approval.
    c. Ground conditions shall be free of extensive flooding or any other type of inundation.
    d. Leaf-off conditions: leaf-off vegetation conditions are preferred. Consideration will be given to factors beyond human control that may affect dormant conditions at the time of collection. LiDAR penetration to the ground will be ensured in order to adequately produce an accurate and reliable bare-earth surface for the prescribed QL (see Section II.3 above and Section VII).

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.
3. GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse. Adjusted GPS Time is defined to be Standard (or satellite) GPS time minus $1x10^9$. See the LAS Specification for more detail. (http://www.asprs.org/wp-content/uploads/2010/12/LAS_1_4_r13.pdf).
4. All mapping products will be delivered in Kentucky Single Zone State Plane Coordinate System (SPCS) coordinates (parameters defined in FIPS 1600, and units of U.S. Survey Feet), NAD83* geometric datum (NSRS2007 or CORS96 adjustment)
5. 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 GEOD12A* model).

    [Use the most current adjustment and geoid model available from the National Geodetic Survey at time of data processing]*

6. Point families (multiple return "children" of a single "parent" pulse) will be maintained throughout all processing before tiling. Multiple returns from a given pulse will be stored in sequential (collected) order.
7. Unless otherwise required by the data producer, LiDAR swaths may be of any file size supported within a 64-bit computing system. In cases where segmentation of the swaths is required by the data producer, the following requirements apply:
   a. Subswath segments of a given original swath will be of comparable size.
   b. Each subswath shall retain the File Source ID of the original complete swath.
   c. Points within each subswath shall retain the Point Source ID of the original complete swath.
   d. Each subswath file shall be named identically to the original complete swath, with the addition of an ordered alphabetic suffix to the name ("-a," "-b," …, "-n"). The order of the named subswaths shall be consistent with the collection order of the points ("-a" will be the first subswath; "-n" will be the last subswath).
   e. Point families will be maintained intact within each subswath.
   f. Subswaths will be broken at the edge of the scan line.
8. All collected swaths shall be delivered as part of the Raw Data Deliverable, including, calibration swaths and cross-ties. All collected returns within each swath shall also be delivered. No points are to be deleted from the swath LAS files. Exceptions to this rule are the extraneous data outside of the BCR (such as aircraft turns, transit between the BCR and airport, and transit between fill-in areas). These points may be permanently removed from swaths. Swaths that are being completely discarded by the vendor and reflown do not need to be delivered.
9. Within each LAS file, points from a given swath shall be stored together and in their collected order.
10. 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.
    a. This applies primarily to points which are identified during pre-processing or through automated post-processing routines.
    b. "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.
11. Minimum classified point cloud classification scheme: it is required as it appears in
    http://www.asprs.org/wp-content/uploads/2010/12/LAS_1_4_r13.pdf

(table 6, page 11). Additional classes may be required on specific projects. The following requirements apply to point classification:

a. In the raw LAS deliverable, no classifications are required; however, Overage (overlap) and Withheld Flags will be properly set.
b. In the Classified LAS deliverable,All points not identified as Withheld shall be classified.
c. No points in the Classified LAS deliverable shall remain assigned to Class 0.
d. Overage points shall only be identified using the Overlap Flag, as defined in:
 http://www.asprs.org/wp-content/uploads/2010/12/LAS_1_4_r13.pdf

12. Overlap: Use of the point classification field in any way for overage/overlap identification is prohibited.
    a. The Overlap Classification (class value = 12) shall not be used.
    b. ALL points not tagged as “Withheld” are to be classified.
    c. 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.
13. Before classification of and development of derivative products from the point cloud, the absolute and relative vertical accuracy of the point cloud shall be verified. A detailed report of the validation processes used shall be delivered (see Section V).
14. 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 1% of non-withheld 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 KYAPED program determines classification to be difficult.
15. Tiles:

    Note: This section assumes a projected coordinate reference system.

    a. Tiling scheme: the elevation data derived shall be divided into smaller non-overlapping areas or tiles. The tiling scheme for indexing the project area, sub-areas and project regions will be organized as representing “tiles” corresponding to the 5K x 5K US Survey Feet (SPCS) Kentucky tiling scheme grid (http://kygisserver.ky.gov/geoportal/catalog/search/resource/details.page?uuid=%7B082ADE6B-28D3-4399-A963-E299346E3A5B%7D)
    b. Tiles shall be accompanied by an index sheet and as a feature class in a file geodatabase suitable for loading into ArcGIS. The index sheet shall include tile boundary and filename. The Index sheet collar

shall include a graticule with latitude and longitude reference coordinates and the 5K x 5K grid.

c. Tile size must be an integer multiple of the cell size of raster deliverables.
d. Tiled deliverables shall conform to the tiling scheme, without added overlap.
e. Tiled deliverables shall edge-match seamlessly in both the horizontal and vertical.
f. The tile extent and grid shall be approved per project region.

IV. HYDRO-FLATTENING REQUIREMENTS

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

1. Inland Ponds and Lakes:
    a. Approximately 1-acre or greater surface area (approx. 250' diameter for a round pond)
    b. Flat and level water bodies (single elevation for every bank vertex defining a given water body).
    c. The entire water surface edge must be at or just below the immediately surrounding terrain.
    d. 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:
    a. 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.
    b. Flat and level bank-to-bank (perpendicular to the apparent flow centerline).
    c. The entire water-surface edge shall be at or below the immediately surrounding terrain.
    d. Flattened streams and rivers shall present a gradient downhill water surface, following the immediately surrounding terrain.
    e. 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.
    f. The entire water surface edge must be at or just below the immediately surrounding terrain.
    g. 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

the 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:
   a. Represented only as an edge or edges within the project region; collection does not include the opposing shore.
   b. The entire water surface edge must be at or below the immediately surrounding terrain.
   c. 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. Islands: permanent islands 4,000 m2 (1 acre) or larger shall be delineated within all water bodies.
5. 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:
   a. All vertices along single-line stream breaklines are at or below the immediately surrounding terrain
   b. 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 National Elevation Dataset (NED).
6. 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:
   a. 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 Digital Terrain Model (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.
   b. 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.
   c. 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

   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 Federal Geographic Data Committee (FGDC) standards, which facilitate the development, sharing, and use of geospatial data. Metadata deliverables shall include the following:

   a. A collection report detailing mission planning and flight logs
   b. A survey report detailing the collection of all ground control, including the following:
      i. Control points used to calibrate and process the LiDAR and derivative data.
      ii. Check points used to validate the LiDAR point data or any derivative product.
   c. A processing report detailing calibration, classification, and product generation procedures including methodology used for breakline collection and hydro-flattening. *See Sections IV and VI* for more information on hydro-flattening.
   d. A QA/QC report, detailing procedures for analysis, accuracy assessment and validation of the following:
      i. Point data (absolute vertical accuracy [NVA], relative vertical accuracy)
      ii. Bare-earth surface (absolute vertical accuracy [NVA] and [VA])
      iii. Other optional deliverables as appropriate.
   e. 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 Triangulated Irregular Network (TIN) artifacts or raster void areas. A union of tile boundaries or minimum bounding rectangles is not acceptable. For the point clouds, no line segment in the boundary will be further than the four times the ANPS from the nearest LiDAR point. An Esri polygon shapefile or geodatabase is required.
   f. Product metadata (FGDC-compliant, XML format metadata). One XMLfile is required for each of the following datasets:
      i. The overall DPR - describing the DPR, the BPR, the intent of the collection, the types of data collected as part of the project, the various deliverables for the project, and other project-wide information.

ii. Each Lift—Describing the extents of the lift, the swaths included in the lift, locations of GPS base stations and control for the lift, preprocessing and calibration details for the lift, adjustment and fitting processes applied to the lift in relation to other lifts, and other lift-specific information.
iii. Each deliverable product group—Classified point data.
iv. Bare-earth DEMs.
v. Breaklines.
vi. Any other datasets delivered (digital surface models [DSM], intensity images, height above ground surfaces, and others).

g. A block of LiDAR-related metadata tags specified by the USGS shall be included in FGDC metadata files for all LiDAR point data deliverables. All tags are required. 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.
h. FGDC-compliant metadata shall be provided in extensible markup language (.xml) format for each tile of each deliverable (e.g. .las, DEM)

   The following site contains information pertaining to the content and creation of the required metadata:
   ftp://ftpext.usgs.gov/pub/cr/mo/rolla/release/xmlinput/
   On that site, the file **XmlInput1_64.zip** contains the application designed to define and support production of FGDC-compliant metadata, with examples.

   i. Tile-based and Project-level metadata suitable for publication to the Kentucky GeoPortal (http://kygisserver.ky.gov/geoportal/catalog/main/home.page will be also delivered, based on XML sample files provided by the Division of Geographic Information.

2. Raw Point Cloud

   Delivery of the raw point cloud is a requirement for KYAPED projects. Raw point cloud deliverables shall include or conform to the following procedures and specifications:

   a. All collected points, fully calibrated, georeferenced, and adjusted to ground, organized and delivered in their original swaths, one file per swath, one swath per file.
   b. If production processing required segmentation of the swath files, the requirements listed in the section “Swath Size and Segmentation,” shall be met.
   c. Fully compliant LAS Specification version 1.4, Point Data Record Format 6, 7, 8, 9, or 10.
   d. If collected, waveform data in external auxiliary files with the extension .wdp. *See* the LAS Specification version 1.4 for additional

information (http://www.asprs.org/wp-content/uploads/2010/12/LAS_1_4_r13.pdf

e. Correct and properly formatted georeference information as Open Geospatial Consortium (OGC) well known text (WKT) in all LAS file headers.
f. GPS times recorded as Adjusted GPS Time at a precision sufficient to allow unique timestamps for each pulse.
g. Intensity values, normalized to 16-bit. *See* the LAS Specification version 1.4 for additional information (http://www.asprs.org/wp-content/uploads/2010/12/LAS_1_4_r13.pdf)
h. A report of the assessed relative vertical accuracy of the point cloud (smooth surface repeatability and overlap consistency). Relative vertical accuracy requirements are listed in table 2. Raw swath point cloud data shall meet the required accuracy levels before point cloud classification and derivative product generation.
i. A report of the assessed absolute vertical accuracy (NVA only) of the unclassified LiDAR point data in accordance with the guidelines set forth in the Positional Accuracy Standards for Digital Geospatial Data (American Society for Photogrammetry and Remote Sensing, http://www.asprs.org/wp-content/uploads/2015/01/ASPRS_Positional_Accuracy_Standards_Edition1_Version100_November2014.pdf).
j. Raw swath point cloud data shall meet the required accuracy levels before point cloud classification and derivative product generation

3. Classified Point Cloud

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

Classified point cloud deliverables shall include or conform to the following procedures and specifications (See http://dx.doi.org/10.3133/tm11B4 for additional information):

a. All project swaths, returns, and collected points, fully calibrated, adjusted to ground, and classified, by tiles.
b. Project swaths exclude calibration swaths, cross-ties, and other swaths not used and not intended to be used, in product generation.
c. Fully compliant LAS Specification version 1.4 Point Data Record Format 6, 7, 8, 9 or 10.
d. If collected, waveform data in external auxiliary files with the extension .wdp.
e. Correct and properly formatted georeferenced information as Open Geospatial Consortium (OGC) WKT included in all LAS file headers.
f. GPS times recorded as Adjusted GPS Time at a precision sufficient to allow unique timestamps for each pulse.
g. Intensity values, normalized to 16-bit
h. Tiled delivery, without overlap, using the project tiling scheme.

i. Classification, as defined in http://dx.doi.org/10.3133/tm11B4 (table 6, page 11) at a 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 they be excluded during Digital Elevation Model (DEM) generation.

4. Bare Earth Surface (Raster DEM)

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

Bare-earth surface deliverables shall include or conform to the following procedures and specifications:

a. Bare-earth DEM, generated to the limits of the BPR.
b. DEM resolution will be 2 feet, as indicated in guidelines provided for QL2 in: http://dx.doi.org/10.3133/tm11B4 (table 7, page 15).
c. Absolute vertical accuracy requirements for QL2 using the ASPRS methodology for the bare-earth DEM are listed in: http://dx.doi.org/10.3133/tm11B4 (table 5, page 10); i.e. $RMSE_z$ ≤10.0 cm; NVA (95% percentile) ≤19.6 cm; VVA (95% percentile) ≤29.4 cm.
d. Delivery in an industry-standard, GIS-compatible, 32-bit floating point raster format (ERDAS .IMG preferred)
e. Georeference information shall be included in raster file
f. Tiled delivery, without overlap
g. DEM tiles will show no edge artifacts or mismatch
h. A quilted appearance in the overall DEM surface will be cause for rejection of the entire DEM deliverable, whether the rejection is caused by differences in processing quality or character among tiles, swaths, lifts, or other nonnatural divisions.
i. No tiles with void (i.e. "NODATA") areas will be accepted
j. Void areas (for example, areas outside the BCR 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).

k. A report on the assessed absolute vertical accuracy of the bare-earth surface in accordance with the guidelines set forth in: http://dx.doi.org/10.3133/tm11B4.
l. Bridges removed from the surface (refer to the glossary for the definition of a bridge).
m. Road or other travel ways over culverts intact in the surface (refer to the glossary for the definition of a bridge).
n. QA/QC analysis materials for the absolute vertical accuracy assessment.
o. Depressions (sinks), natural or man-made, are not to be filled (as in hydro-conditioning and hydro-enforcement).
p. Water Bodies (ponds and lakes), wide streams and rivers ("double-line"), and other non-tidal water bodies 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 region regardless of size.
q. Hydro-flattening as outlined in Sections IV and VI. The methodology used for hydro-flattening is at the discretion of the data producer

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

5. 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.

Breakline deliverables shall include or conform to the following procedures and specifications:

a. All breaklines developed for use in hydro-flattening shall be delivered as an Esri shapefile or file geodatabase formats, as PolylineZ or PolygonZ feature classes (this is the preferred format), as appropriate to the type of feature represented and the methodology used by the data producer.
b. Each feature class will include properly formatted and accurate georeference information in the standard location
c. Breaklines developed to the limit of the BPR.
d. Breakline elevations will use the same coordinate reference system (horizontal and vertical) and units as the LiDAR point delivery.

e. Properly formatted and accurate georeferenced information for each feature class, stored in that format's standard file system location
f. Each shapefile shall include a correct and properly formatted .prj file.
g. 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.
h. 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 to effectively re-create the delivered DEMs using the LiDAR points and breaklines without substantial editing.

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 HYDRO-FLATTENING REFERENCE

The subject of variations of LiDAR-based digital elevation models (DEM) is somewhat new and substantial diversity exists in the understanding of the topic across the industry. The material presented here was developed to provide a definitive reference on the subject only as it relates to the creation of DEMs intended to be integrated into the U.S. Geological Survey (USGS) National Elevation Dataset (NED). The information presented here is not meant to supplant other reference materials and should not 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 NED. **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 DTM. A hydro-flattened DEM is a topographic DEM and should not 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 NED 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 NED must also possess the same basic character as the existing NED.

A traditional topographic DEM such as the 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 manmade feature). Bridges, manmade 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 water bodies, coastlines, and single- and double-line stream 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 water body 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 post processing for corrections of the final orthophotos. These are special use DEMs and are not relevant to this specification.]

Computer technology allows hydraulic and hydrologic 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:

a. **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.

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

Unlike the DTM, LiDAR data consists solely of mass points; breaklines are not automatically created during LiDAR data collection. Although as mass points, LiDAR is substantially denser than a photogrammetric DTM, it by itself remains limited in its ability to precisely define the boundaries or locations of distinct linear features such as water bodies, streams, and rivers. The lack of breaklines in the intermediate TIN data structure causes triangulation to occur across water bodies, 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. The representation of random irregular water surfaces is wholly unacceptable to the users of the KYAPED 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 well. 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. KYAPED does not require that breaklines be used for flattening, but does require the delivery of breaklines for all flattened water bodies, and any other breaklines developed for each project. See the section IV "Digital Elevation Model Hydro-Flattening" for additional information.

VII COMMON BUY-UP OPTIONS

a. Enhanced QL categories: i.e. QL0, QL1
b. ncreased Vertical Accuracy ($RMSE_Z$) for non-vegetated area in concordance with enhanced QL category of choice (i.e. QL0, QL1; see: http://dx.doi.org/10.3133/tm11B4, table 4, page 10)
c. Full waveform collection and delivery.
d. Top-of-Canopy (first return) Raster Surface (tiled): a raster representing the highest return within each cell is preferred.
e. Intensity images (8-bit gray scale, tiled):
   i. Interpolation based on first returns.
   ii. Interpolation based on all-returns, summed.
f. Detailed Classification (additional classes), as follows:

   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

g. Hydrologically enforced (Hydro-Enforced) digital elevation models (DEM) as an additional deliverable.
h. Hydrologically conditioned (Hydro-Conditioned) DEMs as an additional deliverable.
i. Breaklines (PolylineZ and PolygonZ) for additional hydrographic and topographic features including appropriate integration into delivered DEMs:
    i. Narrower double-line streams and rivers.
    ii. Single-line streams and rivers(narrow streams not collected as double-line).
    iii. Smaller ponds.
    iv. Culverts and other drainage structures.
    v. Retaining walls.
    vi. Hydrologic areas, for example swamp or marsh.
    vii. Appropriate integration of additional features into delivered DEMs.
j. Extracted Buildings (PolygonZ): Footprints with maximum elevation and/or height above ground as an attribute.
k. Completion of remaining, unscheduled portion of administrative unit (county, incorporated city, etc.)
l. Independent 3rd-Party QA/QC by another sub-contractor
m. Additional Environmental Constraints
n. Tidal coordination, flood stages, crop/plant growth cycles, etc.
o. Shorelines corrected for tidal variations within a collection
p. Other products as defined by requirements and agreed upon in advance of funding commitment.

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