

**North Carolina**  
**Technical Specifications for**  
**LiDAR Base Mapping**



Land Records Management Division  
North Carolina Department of  
The Secretary of State

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# **North Carolina Technical Specifications for LiDAR Base Mapping**

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## 1. GENERAL

### 1.01 Light Detection and Ranging (LiDAR) Systems

For the purposes of this Standard, **LiDAR (Light Detection And Ranging)** is defined as an airborne laser system, flown aboard rotary or fixed-wing aircraft, that is used to acquire x, y, and z coordinates of terrain and terrain features that are both manmade and naturally occurring. LiDAR systems consist of an airborne Global Positioning System (GPS) with attendant GPS base station(s), Inertial Measuring Unit (IMU), and light-emitting scanning laser.

The system measures ranges from the scanning laser to terrain surfaces within a scan width beneath the aircraft. The time it takes for the emitted light (LiDAR return) to reach the earth's surface and reflect back to the onboard LiDAR detector is measured to determine the range to ground. Scan widths will vary, depending on mission purpose, weather conditions, desired point density and spacing, and other factors. The airborne GPS component ascertains the in-flight three-dimensional position of the sensor, and the IMU component delivers precise information about the attitude of the sensor: roll, pitch, and yaw. This information provides the origin point of the pulse. The sensor collects the direction and slope of the pulse. It also collects the range of each return. Post processing of this data will generate coordinates for all returns.

See: [http://www.ncfloodmaps.com/pubdocs/LiDAR\\_final\\_jan03.pdf](http://www.ncfloodmaps.com/pubdocs/LiDAR_final_jan03.pdf)

### 1.02 General Guidelines for Use

Important factors to consider in the LiDAR-system mission planning are the desired pulse density required to produce the randomly spaced LiDAR points and the point spacing of the uniformly spaced digital elevation model (DEM) points derived from the randomly spaced LiDAR returns. The correct point density necessary to accurately represent terrain and terrain features will depend on vegetation, structures, flight conditions, mission purpose, and required accuracy. Even with adequate LiDAR points, if the chosen DEM spacing is too large the micro-terrain will not be reflected in the DEM.

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Flight-path planning is another important factor in the LiDAR system mission. The flight path shall cover the study area satisfactorily including both parallel and cross flight lines to eliminate shadowing and allow for proper quality control. Unlike aerial photogrammetry, LiDAR missions can be flown without regard to sun angle. Flights may take place at night, if conditions otherwise allow.

Elevation and measurement information related to subsurface channel and hydraulic structure geometry must be obtained through the use of other mapping technologies. In some instances, shallow, clear water and near-shore coastal surveys can be accomplished using LiDAR systems equipped with lasers operating in portions of the light spectrum that allow transmission through water.

LiDAR system tolerance for inclement weather conditions (e.g., high winds, wet snow, rain, fog, high humidity, low cloud cover) generally is higher than that of other photogrammetric methods. However, such conditions have been known to degrade the accuracy of laser return data. Therefore, the contractor shall generally avoid missions during inclement weather.

In dense foliage, more pulses equate to a greater probability that the return data set will include adequate bare earth coordinates to produce an accurate terrain model. A single pulse may generate multiple returns, depending on how many objects it strikes before it is completely blocked. There is no guarantee that the pulse will reach bare earth. Care must be taken in planning missions with regard to both natural (vegetative) and manmade (structure) ground cover. Pulse width, beam divergence, first and last pulse return discrimination, and choice of the post-processing algorithms may all affect the accuracy of LiDAR-derived data in areas of dense foliage.

## 1.03 Definitions:

### 1.03.1 General Definitions

**1.03.1.1 Client** is the financially responsible entity entering into a mapping contract with a Contractor under the provisions of these specifications. A Client may be a county government, municipal government, any local, state agency or private entity.

**1.03.1.2 The Contracting Officer** is the officially designated representative of the financially responsible entity (Client) obtaining the mapping

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products or other services. This individual's authority and responsibilities shall be as prescribed by the Client.

**1.03.1.3 The Contractor** is that firm, company, or organization to which the mapping or service contract has been let. References to the Contractor in these specifications shall also apply in full to any subcontractor working for the named Contractor.

**1.03.1.4 Mapping Basic Modular Unit:** The 1" = 400' map is the smallest scale map included in these specifications and is designated the "Basic Modular Unit" in a series of maps which provide for four map scales, as follows:

- 1" = 400'. The boundaries of each Basic Modular Unit shall be the grid ticks of the North Carolina State Plane Coordinate System evenly divisible by 10,000 ft. in north-south and east-west directions.
- 1" = 200'. Each map will be one-quarter (1/4) of a Basic Modular Unit. The neat image area shall be bounded by the North Carolina grid ticks whose eastings and northings are evenly divisible by 5,000 feet.
- 1" = 100'. Each map shall be one-sixteenth (1/16) of a Basic Modular Unit. The neat image area of this unit shall be bounded by the North Carolina grid ticks with eastings and northings evenly divisible by 2,500 feet.
- 1" = 50'. Each map shall be one sixty-fourth (1/64) of a Basic Modular Unit. The neat image area of this unit shall be bounded by the North Carolina grid ticks with eastings and northings evenly divisible by 1,250 feet.

## 1.03.2 LiDAR Definitions:

**1.03.2.1 LiDAR** is an acronym for Light Detection and Ranging. LiDAR is synonymous with airborne laser mapping and laser altimetry. A LiDAR sensor is an instrument that measures distance to a reflecting object by emitting timed pulses of laser light and measuring the time between

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emission and reception of reflected pulses. The measured time interval is converted to distance.

**1.03.2.2 Active Sensors** send a pulse of energy and await the return of that energy. Passive sensors, by contrast, record reflected or emitted energy (e.g. thermal sensors) where the sun is the typical source of the energy.

**1.03.2.3 Discrete:** A laser pulse is a beam of light comprising a continuous waveform. When LiDAR systems for mapping were first developed for commercial purposes, the LiDAR sensors were not electronically capable of recording the entire waveform in the return signal. A filter was applied to detect peaks in the reflected waveform and to record the timing of those peaks as discrete “returns”. For example, a peak is generated from a reflection caused by the top of the tree, but a sufficient amount of laser light energy is able to continue on to generate returns from lower parts of the tree, and finally, from the ground. You might think of discrete LiDAR as a digitization of waveform LiDAR. In that sense, when the return waveform is above a certain threshold, the LiDAR system records a discrete pulse - up to five discrete pulses per return.

**1.03.2.4 Waveform:** The entire waveform from the laser pulse is recorded (as opposed to discrete returns). This technique currently has lower spatial resolution than discrete LiDAR but captures more detailed information on vertical structure and can more accurately detect the true ground topography under the dense vegetation canopy. Waveform LiDAR is not subject to signal processing errors.

**1.03.2.5 Multiple-Return LiDAR:** Still further classifications exist within discrete LiDAR: LiDAR can be collected as single return or multiple-return. Single-return LiDAR is cheaper but can only be used to derive a bare earth and a canopy height model. Multiple-return LiDAR is required to assess 3-D forest structure characteristics.

**1.03.2.6 Monochromatic** means it has one wavelength of light - usually in the near-infrared range for terrestrial applications.

**1.03.2.7 Intensity Data:** A LiDAR return is made up of the x, y, and z position of the point. The sensor also records the intensity of the reflected signal; that data can be viewed as an image similar to a panchromatic orthophoto. Because the Lidar pulse is in the near infrared (NIR) spectrum the image will have similarities to NIR. The intensity of the reflection can be affected by a combination of factors such as flying height, laser power and wavelength, atmosphere, direction of the laser beam and the number of returns.

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- 1.03.2.8 Bare Earth** is the digital elevation data of the terrain, free from vegetation, buildings, and other man-made structures. Elevations of the ground are derived from post-processing of LiDAR data. Automated and manual post-processing routines are used to eliminate points that impinge on elevation features.
- 1.03.2.9 Datum:** For digital elevation data produced under the Standard, the horizontal datum (i.e., coordinate system in which control points are located) is the North Carolina State Plane Coordinates system, as defined in the North Carolina Official Survey Base (N.C. G.S. 102) including the latest published adjustment, and the vertical datum (i.e., set of constants defining a height system) is the North American Vertical Datum of 1988 (NAVD 88) (see Appendix I). The most current Geoid model published by National Geodetic Survey shall be used. All data will be based on US Survey Foot unless the contractor has obtained a written waiver from the contracting official; said waiver shall be prominently noted in all deliverables. Elevation will be stated as orthometric height.
- 1.03.2.10 FIRM (Flood Insurance Rate Map)** is an official map of a community on which Federal Emergency Management Agency (FEMA) has delineated the flood hazard areas and the risk premium zones.
- 1.03.2.11 GIS (Geographic Information System):** A system of spatially referenced information, including computer programs that store, manipulate, analyze, and display spatial data.
- 1.03.2.12 GPS (Global Positioning System):** Technology that computes the three-dimensional position in space, for example the LiDAR sensor, using satellites.
- 1.03.2.13 North Carolina Unit of Measurement:** U.S. Survey Foot
- 1.03.2.14 Feet/Meter Conversions:** The U. S. Survey Foot (1 meter = 3.2808333333 feet) shall be used in all conversions of North Carolina State Plane Coordinates from meters to feet or feet to meters. All final control data shall be in U.S. Survey feet and the datum used (See Section 1.03.2.9 Datum) will be noted on any sheets bearing coordinates.
- 1.03.2.15 H&H (Hydrologic & Hydraulic)** is the modeling of rainfall runoff (hydrology), providing peak discharges, and the resulting flow within a channel (hydraulics), which provides a profile of water surface elevations. Digital elevation data are used for H&H analyses.

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- 1.03.2.16 IMU (Inertial Measurement Unit):** Instrumentation that computes the roll, pitch, and heading of a moving object, for example a LiDAR sensor mounted in an aircraft.
- 1.03.2.17 Z-Values:** The elevations of the 3-D surface above the vertical datum at designated X-Y locations.
- 1.03.2.18 Mass Points** is a sub set of the point cloud. Irregularly spaced points, each with X-Y location coordinates and Z-value, typically segregated by some criteria for example first return or bare earth. Mass point spacing and pattern may depend upon the characteristics of the technologies used to acquire and post process the data.
- 1.03.2.19 Point Cloud:** Often referred to as the “raw point cloud”, this is the first data product of a LiDAR instrument. In its crudest form, a LiDAR raw point cloud is a collection of range measurements and sensor orientation parameters. After initial processing, the range and orientation of each laser value is converted to a position in a three dimensional frame of reference and this spatially coherent cloud of points is the base for further processing and analysis. The raw point cloud typically includes first, last, and intermediate returns for each laser pulse. In addition to spatial information, LiDAR intensity returns provide texture or color information. The combination of three dimensional spatial information and spectral information contained in the LiDAR dataset allows great flexibility for data manipulation and extraction. In its refined form all points will have a LAS classification even those deemed noise. (see Section 1.03.2.25)
- 1.03.2.20 Vegetation Removal:** Correction of surface elevations so as to depict the elevation of the bare earth terrain without interference due to above ground objects.
- 1.03.2.21 Artifact Removal:** Correction of surface elevations so as to depict the elevation of the bare earth terrain beneath manmade structures.
- 1.03.2.22 Voids:** Portions of a digital elevation dataset where no elevation data are available.
- 1.03.2.23 LiDAR Preliminary Processing:** The initial processing and analysis of laser data to fully “calibrated point clouds” in some specified tile format. All LiDAR data should be set to the American Society for Photogrammetry and Remote Sensing (ASPRS) LAS Class 1 (unclassified) and it is recommended that testing for Fundamental Vertical Accuracy (FVA) be performed during preliminary processing. The tile format can change later, if necessary.
- 1.03.2.24 LiDAR Post-Processing:** The final processing and classification of LiDAR data to the recommended ASPRS LAS classes, per project

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specifications. It is recommended that testing for Consolidated Vertical Accuracy (CVA) and Supplemental Vertical Accuracy (SVA) be performed after LiDAR post-processing is complete. At this point, the datasets are referred to as the “classified point cloud.”

**1.03.2.25 LASer File Format Exchange (LAS):** The ASPRS LAS file format is a public file format for the interchange of 3-dimensional point cloud data between data users. Although developed primarily for exchange of LiDAR point cloud data, this format supports the exchange of any 3-dimensional X-Y-Z triplet. This binary file format is an alternative to proprietary systems or a generic American Standard Code for Information Interchange (ASCII) file interchange system used by many companies.

[Http://www.asprs.org/society/committees/standards/LAS\\_1\\_4\\_r11.pdf](http://www.asprs.org/society/committees/standards/LAS_1_4_r11.pdf)

**1.03.2.26 Control Point** is any horizontal or vertical ground point established by the contractor for the purpose of validation, project control, and /or quality control.

**1.03.2.27 Daily Calibration Survey** is a survey designed to validate the LiDAR data collected daily by each sensor used that day to collected data at the start and end on each mission by flying the pre-established range. The flight pattern is flown over the test area in two opposing directions and a cross-flight at 90 degrees to the former.

**1.03.2.28 Point Family** consists of multiple returns resulting in a group of points (children) from a single pulse (parent).

**1.03.3 Digital Elevation Data:** Includes all of the following terms: mass points, point clouds, breaklines, contours, TINs, DEMs, DTMs or DSMs.

**1.03.4 Metadata:** A data file that describes other data. It provides information about a certain item's content. For example, an image may include metadata that describes how large the picture is, the color depth, the image resolution, when the image was created, and other data. A text document's metadata may contain information about how long the document is, who the author is, when the document was written, and a short summary of the document. Federal Geographic Data Committee (FGDC) Compliant Metadata is metadata that follows an FGDC approved standard that provides a common set of terminology, definitions, and information about values to be provided in a formally-structured documentation of digital data products.

## 1.03.5 Geospatial Accuracy Standard Definitions

**1.03.5.1 Geospatial Accuracy Standard** – A common accuracy testing and reporting methodology that facilitates sharing and interoperability of geospatial data. Published in 1998, the National Standard for Spatial Data Accuracy (NSSDA) is the Federal Geographic Data Committee (FGDC) standard relevant to digital elevation data when assuming that errors follow a normal error distribution. However, after it was learned that LiDAR datasets do not necessarily follow a normal distribution in vegetated terrain, the National Digital Elevation Program (NDEP) published its “Guidelines for Digital Elevation Data” and the American Society for Photogrammetry and Remote Sensing (ASPRS) published the “ASPRS Guidelines: Vertical Accuracy Reporting for LiDAR Data,” both of which were published in 2004 and use newer terms defined below as Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). All of these standards, designed for digital elevation data, replace the National Map Accuracy Standard (NMAS) that is applicable only to graphic maps defined by map scale and contour interval. See Appendix H.

**1.03.5.2 Accuracy** – The closeness of an estimated value (e.g., measured or computed) to a standard or accepted (true) value of a particular quantity. *Note: With the exception of GPS Continuously Operating Reference Stations (CORS), assumed to be known with zero errors relative to established datums, the true locations of 3-D spatial coordinates or other points are not known, but only estimated. Therefore, the accuracy of other coordinate information is unknown and can only be estimated. Other accuracy definitions are as follows.*

**1.03.5.2.1 Absolute Accuracy** – A measure that accounts for all systematic and random errors in a data set. Absolute accuracy is stated with respect to a defined datum or reference system.

**1.03.5.2.2 Accuracy<sub>r</sub>** is the NSSDA reporting standard in the horizontal component that equals the radius of a circle of uncertainty, such that the true or theoretical horizontal location of the point falls within that circle 95-% of the time. **Accuracy<sub>r</sub>** = 1.7308 x Root Mean Square Error<sub>r</sub> (RMSE<sub>r</sub>). Horizontal accuracy is defined as the positional accuracy of a dataset with respect to a horizontal datum.

**1.03.5.2.3 Accuracy<sub>z</sub>** is the NSSDA reporting standard in the vertical component that equals the linear uncertainty value, such that the

# North Carolina Technical Specifications for LiDAR Base Mapping

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true or theoretical vertical location of the point falls within that linear uncertainty value 95-% of the time.  $\text{Accuracy}_z = 1.9600 \times \text{RMSE}_z$ . Vertical accuracy is defined as the positional accuracy of a dataset with respect to a vertical datum.

## 1.03.5.2.4 Vertical Accuracy

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

**Fundamental Vertical Accuracy (FVA)** is the value by which vertical accuracy can be equitably assessed and compared among datasets. The FVA is determined with vertical checkpoints located only in open terrain, where there is a very high probability that the sensor will have detected the ground surface. FVA is calculated at the 95% confidence level in open terrain only, using  $\text{RMSE}_z \times 1.9600$ ,

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

**1.03.5.2.5 Local Accuracy** – A value that represents the uncertainty in the coordinates of a control point relative to the coordinates of other directly-connected, adjacent control points at the 95% confidence level. The reported local accuracy is an approximate average of the individual local accuracy values between this control point and other observed control points used to establish the coordinates of the control point.

**1.03.5.2.6 Network Accuracy** – A value that represents the uncertainty in the coordinates of a control point with respect to the geodetic datum at the 95% confidence level. For National Spatial Reference System (NSRS) network accuracy classification in the U.S., the datum is considered to be best expressed by the geodetic

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values at the CORS supported by the National Geodetic Survey (NGS). By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero.

**1.03.5.2.7 Percentile** – Any of the values in a dataset of errors dividing the distribution of the individual errors in the dataset into one hundred groups of equal frequency. Any of those groups can specify a specific percentile, e.g., the 95th percentile as defined below.

**1.03.5.2.8 Precision** – A statistical measure of the tendency of a set of random numbers to cluster about a number determined by the dataset. Precision relates to the quality of the method by which the measurements were made and is distinguished from accuracy which relates to the quality of the result. The term “precision” not only applies to the fidelity with which required operations are performed, but, by custom, has been applied to methods and instruments employed in obtaining results of a high order of precision. Precision is exemplified by the number of decimal places to which a computation is carried and a result stated.

**1.03.5.2.9 Positional Accuracy** – The accuracy of the position of features, including horizontal and/or vertical positions.

**1.03.5.2.10 Relative Accuracy** – A measure that accounts for random errors in a dataset. Relative accuracy may also be referred to as point-to-point accuracy. The general measure of relative accuracy is an evaluation of the random errors (systematic errors and blunders removed) in determining the positional orientation (e.g., distance, azimuth) of one point or feature with respect to another.

**1.03.5.2.11 Root Mean Square Error (RMSE)** – The square root of the average of the sum of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The vertical RMSE (RMSE<sub>z</sub>), for example, is calculated as the square root of  $S(Z_n - Z'_n)^2/N$ , where: **Z<sub>n</sub>** is the set of N z-values (elevations) being evaluated, normally interpolated (for TINs and DEMs) from dataset elevations of points surrounding the X-Y coordinates of checkpoints; and **Z'<sub>n</sub>** is the corresponding set of checkpoint elevations for the points being evaluated; **-N** is the number of checkpoints; and **n** is the identification number of each of the checkpoints from 1 through N.

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**1.03.5.2.12 95% Confidence Level** – Accuracy reported at the 95% confidence level means that 95% of the positions or elevations in the dataset will have an error with respect to true ground position or true elevation that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates; GPS-IMU system error, sensor error, processing algorithm error, interpolation error, and final computation of ground coordinate values in the product. Where errors follow a normal error distribution,  $Accuracy_z$  defines vertical accuracy at the 95% confidence level (computed as  $RMSE_z \times 1.9600$ ), and  $Accuracy_r$  defines horizontal (radial) accuracy at the 95% confidence level (computed as  $RMSE_r \times 1.7308$ ).

**1.03.5.2.13 95th Percentile** – Accuracy reported at the 95th percentile indicates that 95% of the errors will be of equal or lesser value and 5% of the errors will be of larger value. This term is used when errors may not follow a normal error distribution, e.g., in forested areas where the classification of bare-earth elevations may have a positive bias. Vertical accuracy at the 95% confidence level and 95th percentile may be compared to evaluate the degree to which actual errors approach a normal error distribution. See “Issue 37: Quality Control of Light Detection and ranging (LiDAR) Elevation Data in North Carolina for Phase II of the NCFMP” .

[http://www.ncfloodmaps.com/pubdocs/issue\\_papers/IP37-phaseII\\_lidar\\_qc.pdf](http://www.ncfloodmaps.com/pubdocs/issue_papers/IP37-phaseII_lidar_qc.pdf)

**1.03.5.3 Resolution** – In the context of elevation data, resolution is synonymous with the horizontal density of elevation data points for which two similar terms are used; Nominal Pulse Spacing and Nominal Point Spacing.

**1.03.5.3.1 Nominal Pulse Spacing (NPS)** is the estimated average spacing of irregularly-spaced LiDAR points in both the along-track and cross-track directions resulting from: the laser pulse repetition frequency (e.g., 100,000 pulses of laser energy emitted in one second from a 100 kHz sensor); scan rate (sometimes viewed as the number of zigzags per second for this common scanning pattern); field-of-view; flight airspeed, and flight altitude above the terrain. LiDAR system developers currently provide “design NPS” as part of the design pulse density, although the American Society for Photogrammetry and Remote Sensing (ASPRS) is

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currently developing standard procedures to compute the “empirical NPS” which should be approximately the same as the “design NPS” when accepting statistically insignificant loss of returns and disregarding void areas, from water for example. The NPS assessment is made against single swath first return data located within the geometrically usable center portion (typically ~90%) of each swath. Average along-track and cross-track pulse spacing should be comparable. When point density is increased by relying on overlap or double-coverage it should be documented in metadata, and the project’s reported NPS should not change. The NPS should be equal to or less than the desired Digital Elevation Model grid. NPS is not to be substituted for Nominal Point Spacing.

**1.03.5.3.2 Nominal Point Spacing** is not an appropriate term in LiDAR because a single Pulse can produce multiple points. NPS as used in this standard pertains to LiDAR only and is not intended to pertain to photogrammetry or Interferometric Synthetic Aperture Radar (IFSAR).

## 1.03.6 Derived Products Definitions

**1.03.6.1 Bare Earth DEM (Digital Elevation Model):** A popular acronym used as a generic term for digital topographic and/or bathymetric data in all its various forms, but most often bare earth elevations at regularly spaced intervals in X and Y directions. Regularly spaced elevation data are easily and efficiently processed in a variety of computer uses. A DEM contains elevations at points arranged in a raster data structure, a regularly spaced X, Y grid, where the intervals of  $\Delta X$  and  $\Delta Y$  are normally in linear units (feet or meters) or geographic units (degrees or fractions of degrees of latitude or longitude). The Z-values in a DEM represent the height of the terrain, relative to a specific vertical datum and void of vegetation or manmade structures such as buildings, bridges, walls, et cetera. The elevation of lakes and rivers in a DEM implies the height of the water surface based on elevation of the exposed shoreline. The observations, or direct measurements, of elevation that comprise the DEM are almost never actually captured on a regular grid; therefore, the elevation for any given point in the grid is normally interpolated from other forms of source data. LiDAR, for example, yields a dense set of irregularly spaced points; interpolation to a grid requires using one of many possible interpolation algorithms, which produce varying results. Linear features, such as streams,

drainage ditches, ridges, and roads are often lost in a DEM if the grid spacing is larger than the dimensions of the feature. Furthermore, in a DEM, it is unlikely that the hard edge of the feature will be represented correctly in the terrain model. The DEM, because it is a raster data structure similar to a digital image, is an efficient format for storage, analysis, rendering, and visualization.

**1.03.6.1.1 DEM post spacing** is defined as the constant sampling interval in X- and Y-directions of a DEM lattice or grid. This is also called the horizontal resolution of a gridded DEM or the DEM grid spacing. If a DEM is required as part of project specifications the contract must include the desired grid spacing. It is standard industry practice to have:

- 1-meter DEM post spacing for elevation data with 1-foot equivalent contour accuracy;
- 2-meter DEM post spacing for elevation data with 2-foot equivalent contour accuracy; and
- 5-meter DEM post spacing for elevation data with 5-foot equivalent contour accuracy.

**1.03.6.2 Digital Terrain Model (DTM)** data structure is also made up of X and Y points with Z-values representing elevations, but unlike the DEM, these may be irregularly or randomly spaced mass points. Direct observations of elevation at a particular location can be incorporated without interpolation, and the density of points can be adjusted so as best to characterize the actual terrain. Fewer points can describe very flat or evenly sloping ground; more points can be captured to describe very complicated terrain. In addition to mass points, the DTM data structure often incorporates breaklines (further defined below) to retain abrupt linear features in the model. A DTM is often more expensive and time consuming to collect than a DEM, but is considered technically superior for most engineering analyses because it retains natural features of the terrain.

**1.03.6.3 Digital Surface Model (DSM)** is an elevation model created for use in computer software that is similar to DEMs or DTMs except that DSMs depict the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare earth.

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

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**1.03.6.5 Contours** are lines of equal elevation on a surface. An imaginary line on the ground, all points of which are at the same elevation above or below a specified reference surface (datum).

**1.03.6.6 Breakline** is a linear feature demarking a change in the smoothness or continuity of a surface such as abrupt elevation changes or a stream line. The two most common forms of breaklines are as follows:

**1.03.6.6.1 Soft breakline** ensures that known elevations, or Z-values, along a linear feature are maintained (e.g., elevations along a pipeline, road centerline, or drainage ditch), and ensures the boundary of natural and man-made features on the Earth's surface are appropriately represented in the digital terrain data by use of linear features and polygon edges. They are generally synonymous with 3-D breaklines because they are depicted with series of Z-Y-Z coordinates.

**1.03.6.6.2 Hard breakline** defines interruptions in surface smoothness, e.g., to define streams, shorelines, dams, ridges, building footprints, and other locations with abrupt surface changes. Although some hard breaklines are 3-D breaklines, they are often depicted as 2-D breaklines because features such as shorelines and building footprints are normally depicted with a series of horizontal coordinates only, that are often digitized from digital orthophotography that include no elevation data.

**1.03.6.7 Triangulated Irregular Network (TIN)** is a set of adjacent, non-overlapping triangles computed from the mass points and breaklines in a DTM. TINs also preserve abrupt linear features and are excellent for calculations of slope, aspect, and surface area and for automated generation of topographic contours, which are all important functions to the flood study engineering. Storage formats for TINs are more complex than either DEMs or DTMs, because the relationship of elevation points and triangular surfaces must be preserved within the data structure. A TIN model may be preferable to a DEM when it is critical to preserve the location of narrow or small surface features such as a stream channel or ridge line.

**1.04 North Carolina Legislative Requirements** - All Data must be collected and processed under the supervision of a Professional Land Surveyor licensed in North Carolina and in accordance with:

*Note: Laws and administrative code affecting this standard may be changed without notice. For the current Statute or Code wording consult the official legislative or licensing board website.*

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## 1.04.1 North Carolina Surveying Law N.C. G.S. 89C

[http://www.ncleg.net/EnactedLegislation/Statutes/HTML/ByChapter/Chapter\\_89C.html](http://www.ncleg.net/EnactedLegislation/Statutes/HTML/ByChapter/Chapter_89C.html)

## 1.04.2 NC Board of Registration Administrative Code

<http://reports.oah.state.nc.us/ncac.asp?folderName=\Title%202021%20-%20Occupational%20Licensing%20Boards%20and%20Commissions\Chapter%2056%20-%20Engineers%20and%20Surveyors>

See 21 NCAC 56 .1606 SPECIFICATIONS FOR TOPOGRAPHIC AND PLANIMETRIC MAPPING, INCLUDING GROUND, AIRBORNE, AND SPACEBORNE SURVEYS

See 21 NCAC 56 .1607 GLOBAL POSITIONING SYSTEMS SURVEYS

## 1.04.3 Procurement of Architectural, Engineering and Surveying Services NC GS 143-64.31 (Mini-Brooks Act)

[http://www.ncleg.net/EnactedLegislation/Statutes/HTML/BySection/Chapter\\_143/GS\\_143-64.31.html](http://www.ncleg.net/EnactedLegislation/Statutes/HTML/BySection/Chapter_143/GS_143-64.31.html)

**1.05 North Carolina File Naming Convention** - The “Naming Convention for Geospatial Data presented in the North Carolina Grid Panel Scheme” is an outgrowth of the naming specification found in the North Carolina Technical Specifications for Digital Orthophoto base mapping, August 20, 2009. For lack of a better term consider the use of this naming scheme as “extra-lite” metadata. This convention using the base modular unit from the above standard is consistent with county mapping standards for the last 20 years and compatible with the Parcel Identifier Number (PIN) used for most county tax mapping in North Carolina. This convention is for all types of geospatial data (raster, vector, point, etc.) as long as the data is geo-segregated by grid panel.

### 1.05.1 Name Format:

**LG1m0\_37\_000\_20765400\_20100601R0 :**

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## LG -2-digit product code:

- OC (O = Orthoimagery, C = color)
- OB (O = Orthoimagery, B = Black and White)
- O4 (O = Orthoimagery, 4 = 4 Band)
- OR (O = Orthoimagery, R = Infrared)
- DL (D = Digital Elevation Model, L = LiDAR)
- DP (D = Digital Elevation Model, P = Photogrammetric)
- LA (L = LiDAR Point Data, A = All Return)
- LF (L = LiDAR Point Data, F = First Return)
- LG (L = LiDAR Point Data, G = Ground or Bare Earth)
- LI (L = LiDAR Point Data, I = Intensity)
- LW (L = LiDAR Point Data, W = Waveform)
- HL (H = Hill Shade Model, L = LiDAR)

Note: Codes for other datasets will be added as needed. If the product is a primary deliverable of a technology process, use the technology code as the first character. If the product is a derived product from a technology process, use the product term as the first character and the technology process as the second character.

**1.05.1.1 1m0 – 3-digit pixel size or post spacing:** XuD, with X = resolution before a decimal place, u = unit, D = decimal amount of resolution. Use the unit indicator code (i = Inch, f = Foot, m = Meter, c = Centimeter) as the decimal point. 6 Inch = 6i0, 1.5 feet = 1f5, 1.5 meter = 1m5, 15 centimeters = 15c. Note the unit indicator code is always lower case.

- 6u0 = pixel size, u= unit indicator code
- 6i0 = 6 inches.
- 1f0= 1foot,
- 1m5= 1.5 meter,
- 15c = 15 centimeters, etc.

**1.05.1.2 37 – 2-digit NC ANSI (FIPS) Code :** The North Carolina ANSI (FIPS) Code will be used for all data using the North Carolina Grid paneling convention to facilitate its incorporation into national mapping systems.

**1.05.1.3 000 – 3-digit alphanumeric custodian code:**

- For county maintained data this would be county ANSI (FIPS) code,

<http://www.lib.ncsu.edu/gis/countfips.html>

<http://www.census.gov/geo/www/fips/fips65/download.html>

- 000 for statewide,

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- city code (RAL)
- agency code (DOT)

**1.05.1.4 20765400** – Map Index Number -8-digit SOS LRM Numbering of the Basic Modular Unit with Millionth place digits. As in the NC Floodplain Mapping Program, the final two digits are reserved for the two-digit indication of scale and location within the Basic Modular Unit.(see Section 1.05.2)

**1.05.1.5 20100601R0** – 10-digit tile project date (YYYYMMDD)(RN)  
(RN=revision number, 0 is no revisions, R1,R2, etc. to be used as needed.)

**1.05.1.6 Additional user generated info** can be appended at the **END** of the file name; an underscore will be used between the date field and the additional information. While there is no limitation to the number of characters a user can append to a file name, users must be cognizant that the maximum length of a file name (which typically includes the entire file path and not just the file name) can be limited by an operating system or software application.

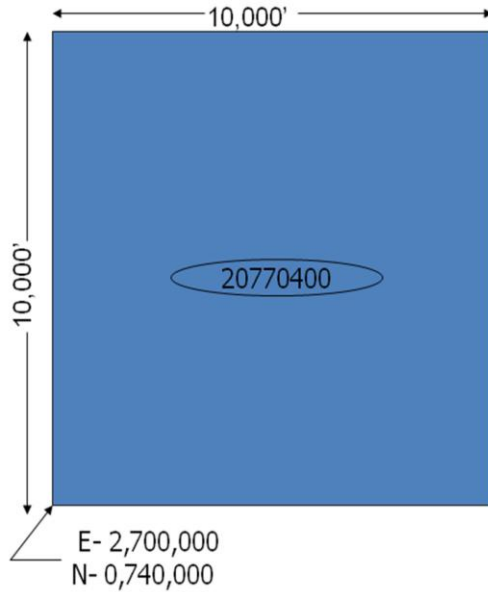
**1.05.2 Basic Modular Unit with Millionth-Place Digits** is an eight-digit SOS LRM number. As in the NC Floodplain Mapping Program, the final two digits are reserved for the two-digit indication of scale and location within the Basic Modular Unit.

- 10,000 x10,000 Map Panel Graphic Layout of Integer Codes  
Ex. 20770400

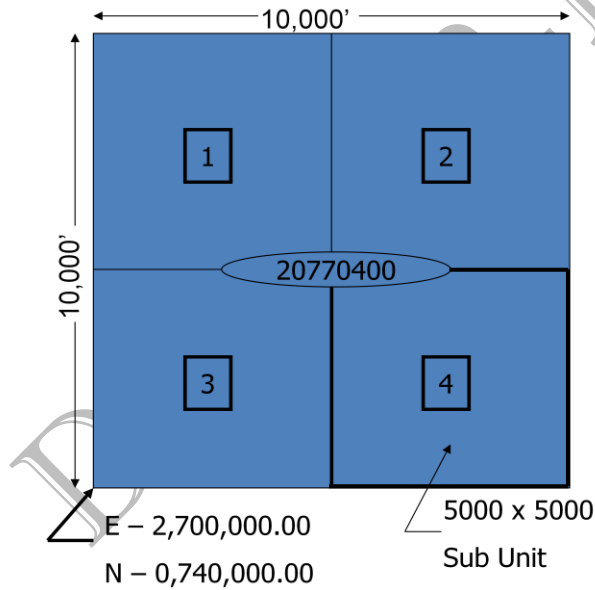
**File name:** OC6i0\_37\_000\_20770400\_20100601R0.tif

**1.05.2.1** 10,000 x10,000 Map Panel Graphic Layout of Integer Codes  
Ex. 20770400

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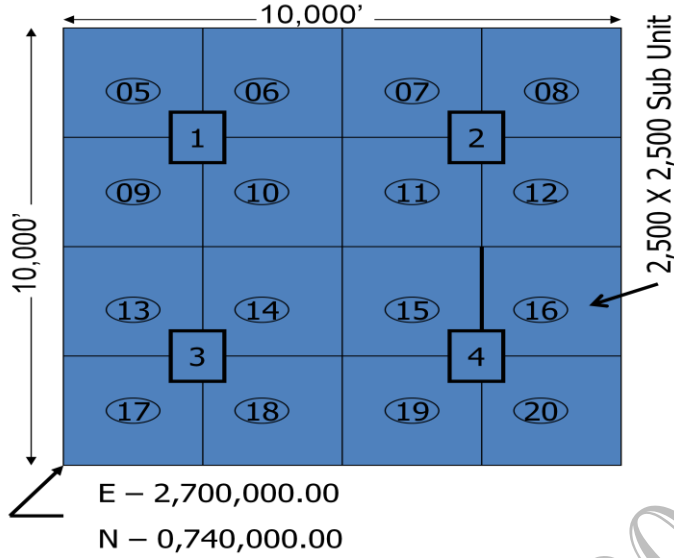


**1.05.2.2** ■ 5,000 x 5,000 Map Panel Graphic Layout of Integer Codes  
Ex. 20770404

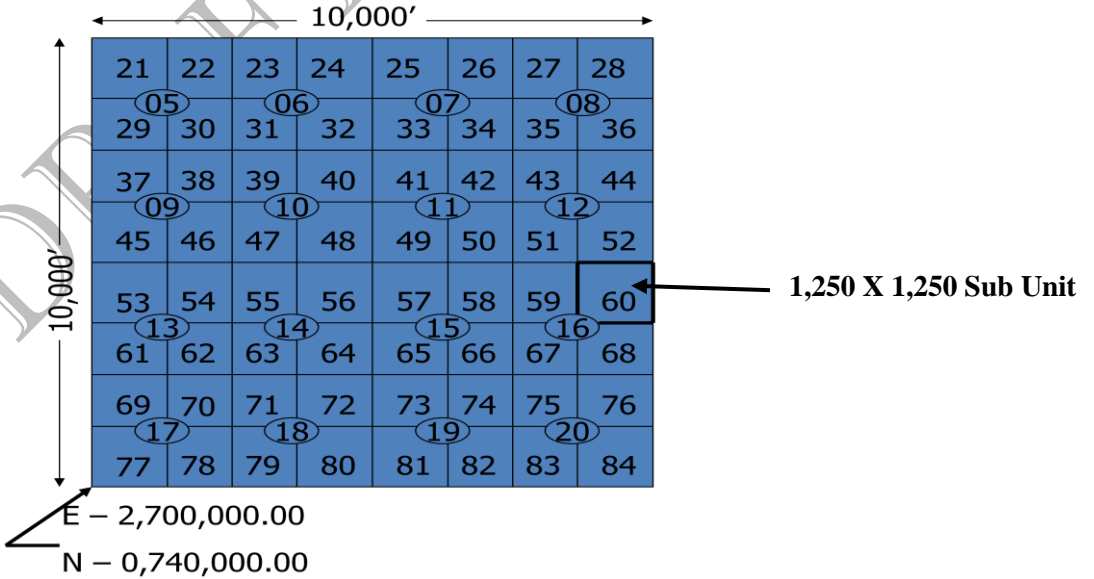


**1.05.2.3** ■ 2,500 x 2,500 Map Panel Graphic layout of Integer Codes  
Ex. 20770416

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**1.05.2.4** ■ 1,250 x 1,250 Map Panel Graphic layout of Integer Codes  
Ex. 20770460



*Note: For a full background of the naming convention (See Appendix D)*

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## 2 CONTRACT MANAGEMENT

### 2.01 **Sample Request for Qualifications (RFQ), Example: (See Appendix A)**

**2.02 Work Statement:** The Contractor shall furnish all materials, superintendence, labor, equipment, and transportation and shall execute and complete all of the work required by the contract in conformance with these specifications and any contractual modifications to these specifications. Any deviation from these specifications, unless specifically authorized in writing by the Contracting Officer or his representative, shall be sufficient cause for rejection of any part or all of the work performed. If a contract change is not approved by the Contracting Officer in writing, said change will not be considered for payment.

**2.03 Product Ownership and Contractor Product Retention Requirements:** The digital data files and any interim and final products are the property of the Client. The Contractor will be responsible for storage of digital data files under proper file maintenance and backup procedures for a period of at least 5 years at no cost to the Client. Digital data should be stored on negotiated media, portable hard drives, secure FTP, DVD+/-R, DVD-ROM, CD-R, CD-ROM, or DLT. All digital media should be readable by both Windows and UNIX systems. All digital media should contain finalized closed sessions, no multi-session discs. All digital media should be properly labeled. If CD or DVD type media is used standard cases (no slim-line or non-standard cases) will be accepted. The Contractor shall not make, sell, or loan copies of the digital files or any other products without the expressed written approval of the Contracting Officer. The film or data file shall be handled carefully before, during, and after authorized use to ensure that the quality is not degraded and is safeguarded from defects. It is the Contractors' obligation to inform the Client if he is no longer able to meet the 5-year storage requirement and provide an opportunity to transfer the records to the Client or their designee. This includes any change in ownership of the Contractor or inability to meet the 5-year storage requirement due to the Contractor going out of business.

**2.04 IT Computer Requirements:** Prior to contracting for a LiDAR Project the client should inventory the Hardware resources available to be used to house and work with the project deliverables. It is common that for an all return point cloud to require several terabytes of storage. This does not include the derived products that might also be contracted for, i.e., elevation terrain model, hill shade model, contours, etc. Adequate storage with built in redundancy such as a Raid system, a functioning backup system, offsite storage, an archive plan and adequate processing

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power are the fundamental elements in an IT system. The client should at a minimum review :

- Hardware Requirements
- Software Requirements
- Long Term Storage Requirements
- Disaster Recovery Backup
- Archiving of Data. Including archiving of source and/or raw data. (Note: A Backup system is not an Archive system.)

## 3 LiDAR ACQUISITION

### 3.01 LiDAR Project Parameters

**3.01.1 Project Boundaries:** Project boundaries shall be defined on a project map in North Carolina state plane coordinates (see section 1.03.2.9 Datum). Said map shall have the appropriate State tiling scheme as an overlay. The project map will be in a digital GIS format, i.e. shapefile or other format suitable to the Contracting Officer, a paper or PDF map may be included as well.

#### **3.01.2 Principal Contract Deliverables:**

- 3.01.2.1** Point Data: Fully compliant LAS V1.2 or V1.3 or greater, Point Record format 1,3,4,5, (or equivalent record format). LAS Version shall be stated in the contract, said version will be determined pursuant to the Clients needs. Note, if the Contracting Officer feels that the client will have difficulty extracting the Bare Earth Points from the point data, he may request a Bare Earth Point Dataset as an additional deliverable.
- 3.01.2.2** Waveform Data (if required)
- 3.01.2.3** Intensity Data (image file)
- 3.01.2.4** Low confidence area polygons (shape file)
- 3.01.2.5** Breaklines (shape file)
- 3.01.2.6** DEM (Digital Elevation Model )(Hydro Flattened)
- 3.01.2.7** FGDC compliant metadata
- 3.01.2.8** QA/QC Reports
- 3.01.2.9** Flight logs

*See Section 9 for a review of required deliverables.*

**3.01.3 Flightline Overlap:** 50% is required unless contracting officer specifies a different overlap. Note: mountainous area or areas with dense vegetation need 50% overlap coverage; other areas may be adequately covered with less overlap. Overlap should not be reduced below 30%.

**3.01.4 Buffering:** Project boundary shall be buffered by a minimum of 2,000 feet. Buffer areas may be adjusted by Contracting Officer.

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**3.01.5 Project Start/Stop Dates:** Leaf-off Conditions: Start and Stop dates determined by local conditions. Dates set by Contracting Officer.

## 4 PRE-PROJECT ACTIVITIES

- 4.01 Sensor Certification:** When a LiDAR sensor is manufactured, the Inertial Reference Systems (INS) and sensor system undergoes laboratory calibration at the factory to establish a very precise vertical alignment. Unless the LiDAR sensor is damaged or modified, this laboratory calibration is done only once. However, each time the LiDAR system is installed, re-installed, or moved within the aircraft, small changes in the alignment may occur, requiring field testing of the calibration parameters. Routine sensor calibration and maintenance are required to ensure proper function of the LiDAR system. LiDAR system components are most effectively tested and calibrated by the equipment manufacturer. Prior to commencing data acquisition, the contractor should provide the factory calibration certification and documentation of preventive maintenance completed either in accordance with the manufacturer's maintenance scheduled , or as justified by apparent lack of calibration stability, whichever interval is shorter. Documentation that recommended firmware/software upgrades have been installed. If the Contractor feels that firmware/software upgrades are too new to be reliable the contractor may apply for a waiver from the Contracting Officer.
- 4.02 North Carolina *In Situ* Validation Range Requirements:** The state of North Carolina has developed a *In Situ* Validation Range for the purpose of validating and/or calibrating sensor systems. The purpose of the *In Situ* range is to validate the sensor in its working environment and ensure that the Contractor(s) can correctly and consistently acquire and quality control data collection, and produce data products that meet specification. Prior to commencing data acquisition, it is recommended that the Contractor acquire data over the validation range, preprocess the data and deliver to the Client for evaluation. This requirement can be waived upon consent of the Contracting Officer.
- 4.03 Daily Calibration Survey:** A daily calibration test course shall be established by the contractor within the project area. **Daily calibration survey** data will be collected by each sensor over this course at the start and end of each flight mission. The calibration sites must be established by ground surveying prior to the collection of any aerial LiDAR data for the projects. GPS base stations and surrounding High Accuracy Reference Network (HARN) points should be used to control redundant RTK GPS surveys and conventional surveys to approximately 8 to 10 calibration points at each site. The calibration site should be selected in an open flat area where elevation ground truth can be unambiguously established. Elevation points should be on smooth, unpainted or bare natural surfaces. Static initialization of the airborne GPS should be performed prior to take-off and upon landing. At minimum three

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flight lines shall be flown over the calibration site for the detection of systematic errors in the airborne GPS/IMU and LiDAR system data. The flight pattern is flown over the test area in two opposing directions and a cross-flight at 90 degrees to the former. A report of the daily calibration results and documentation of calibration points used will be furnished to the Contracting Officer and the quality control team. Any corrective action taken as a result of the daily calibrations shall be included in the report. See Chapter 7 (pages 218-219) of Digital Elevation Model Technologies and Applications: The DEM Users Manual for additional information and [Appendix G: Daily Calibration Survey / Boresight Calibration](#)

**4.04 Flight Line Layout:** A digital map showing the study area boundaries and planned flight path. Documentation specifying altitude, airspeed, scan angle, scan rate, LiDAR pulse rates, receiver return mode, and other flight and equipment information deemed appropriate.

**4.05 Ground Control Map** shall identify which GPS ground control points are used as base stations on particular flight paths with coverage areas and all points used by the contractor for field verification. Said Map shall be in an approved GIS format.

## 5 LiDAR ACQUISITION

*Note: It is conceivable that in some cases, based on specific topography, land cover, intended application, or other factors, the Contracting Officer may require acquisition specifications different than those defined in this document. All changes in specification requirements should be fully documented in project metadata and preapproved in writing by the Contracting Officer.*

### 5.01 Collection

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

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

**5.01.2 Intensity Values** for each return.

**5.01.3 Nominal Pulse Spacing (NPS)** is 1meter, unless the Contracting Officer preapproved in writing a change to the NPS requirement. NPS assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath. Average along-track and cross-track point spacing should be comparable. Collections designed to achieve the NPS through swath overlap or multiple passes are generally discouraged. There are conditions where such collections may be permitted. This should be with prior approval by the Contracting Officer.

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**5.01.4 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; or
- where appropriately filled-in by another swath.

**5.01.5 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  $NPS*2$  will be laid over the data.
- At least 90% of the cells in the grid shall contain at least one LiDAR point.
- Assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.
- 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.*

**5.01.6 Scan Angle:** Total (Field Of View) FOV should not exceed  $40^\circ$  ( $\pm 20^\circ$  from nadir). Quality assurance on collections performed using scan angles wider than  $34^\circ$  FOV will be particularly rigorous in the edge-of-swath areas. Horizontal and vertical accuracy shall remain within the requirements as specified below. *Note: This requirement is primarily applicable to oscillating mirror LiDAR systems. Other instrument technologies may be exempt from this requirement.*

**5.01.7 Cross Scans:** Contracting officer may require periodic flights at approximately 12 mile intervals. Said flights shall be approximately perpendicular to normal flight lines. These swaths will be used to compare continuity of adjacent flight lines during the Q/C.

**5.01.8 Vertical Accuracy** of the LiDAR data will be assessed and reported in accordance with the guidelines developed by the NDEP and subsequently adopted by the ASPRS. The complete guidelines may be found in Section 1.5 of the Guidelines document. See:

[http://www.ndep.gov/NDEP\\_Elevation\\_Guidelines\\_Ver1\\_10May2004.pdf](http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf)

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**5.01.8.1** Vertical accuracy requirements using the NDEP/ASPRS methodology are:

- FVA  $\leq$  24.5cm ACCz, 95% (12.5cm RMSEz) (See Section 1.03.5.2.4 For RMSEz definition)
- CVA  $\leq$  36.3cm, 95th Percentile
- SVA  $\leq$  36.3cm, 95th Percentile

**5.01.9 Point Cloud Accuracy** for the LiDAR data is to be reported independently from accuracies of derivative products (i.e., DEMs). Point cloud data accuracy is to be tested against a TIN constructed from bare-earth LiDAR points.

**5.01.10 Land Cover Testing:** Each land cover type representing 10% or more of the total project area must be tested and reported as a Standard Vertical Accuracy (SVA).

**5.01.10.1** For SVAs, the value is provided as a target. It is understood that in areas of dense vegetation, swamps, or extremely difficult terrain, this value may be exceeded. Overall CVA requirements must be met in spite of "busts" in individual SVAs.

*Note: These requirements may be relaxed in cases:*

- *where there exists a demonstrable and substantial increase in cost to obtain this accuracy;*
- *where an alternate specification is needed to conform to previously contracted phases of a single larger overall collection effort, i.e., multi-year statewide collections, etc.; or*
- *where the contracting officer agrees that it is reasonable and in the best interest of all stakeholders to use an alternate specification.*

*(Note: any alteration to this standard must be approved in writing by the Contracting Officer.)*

**5.01.11 Relative Accuracy**  $\leq$ 7cm RMSEZ within individual swaths;  $\leq$ 10cm RMSEZ within swath overlap (between adjacent swaths).

**5.01.12 Flightline Overlap** of 50% is recommended to ensure there are no data gaps between the usable portions of the swaths unless approved in writing by the Contracting Officer. 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.

**5.01.13 Collection Area:** Defined Project Area, buffered by a minimum of 2,000 feet.

**5.01.14 Collection Conditions:**

**5.01.14.1** Atmospheric: Cloud and fog-free between the aircraft and ground.

**5.01.14.2** Ground:

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- Snow free. Very light, un-drifted snow may be acceptable in special cases, un-melted snow within shadow areas may be acceptable with prior approval of the Contracting Officer.
- No unusual flooding or inundation, (outside of the stream or river banks) except in cases where the goal of the collection is to map the inundation. If contractor suspects that parts of the project area may be flooded the contractor should contact the Contracting Officer for permission to proceed with the project.

**5.01.14.2.1 Vegetation:** Leaf-off, unless project specific requirements dictate otherwise, prior approval by the contracting officer in writing is required. Collections for specific scientific research projects may be exempted from this requirement, with prior approval.

- As numerous factors will affect vegetative condition at the time of any collection, penetration to the ground must be adequate to produce an accurate and reliable bare-earth surface suitable to meet the DEM specifications or density requirements. Any ground hidden areas (i.e., areas obscured by dense vegetation or woods, or areas obscured by overhanging bluffs, ledges or manmade objects) should be delineated by low confidence area polygons. Low confidence areas indicate areas where the vertical data may not meet the data accuracy requirements due to voids within the data set. If the contractor feels that in his professional judgment that contact accuracies cannot be met within an area those areas should be bound by a low confidence area polygon. Said areas should be significant in size to warrant notification of a potential user but small enough as to not jeopardize the integrity of the project.. The Contractor should take reasonable steps to minimize areas delineated as low confidence areas.

## 5.02 Data Processing and Handling

**5.02.1** All processing shall be **performed within the United States of America** or its territories unless the contractor gets prior approval in writing from the Contracting Officer.

**5.02.2** All processing should be carried out with the understanding that all point deliverables are required to be in fully compliant LAS format, v1.2, v1.3 or current ASPRS LAS format standard. The Contracting Officer has final

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determination of LAS format to be used. Data producers are encouraged to review the LAS specification in detail.

- 5.02.3** If full waveform data is collected, **delivery of the waveform packets** is required. LAS v1.3 deliverables with waveform data are to use external “auxiliary” files with the extension “.wdp” for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
- 5.02.4 GPS Times** are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse. Adjusted GPS Time is defined to be Standard (or satellite) GPS Time minus  $1 \times 10^9$ . See the LAS Specification for more detail.
- 5.02.5 Horizontal Datum** shall be referenced to the North Carolina official Survey Base (see section 1.03.2.9). Vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88). The most recent NGS published Geoid model shall be used to perform conversions from ellipsoidal heights to orthometric heights. Mandatory Variable-length Record, GeoKeyDirectory must be populated. This record contains the key values that define the coordinate system.
- 5.02.6** All X, Y, and Z coordinates shall be in **North Carolina State Plane**.
- 5.02.7** All references to the Unit of Measure “Feet” or “Foot” must specify “U.S. Survey” in North Carolina.
- 5.02.8** Long Swaths (those which result in a LAS file larger than 2GB) should be split into segments no greater than 2GB each. Each segment will thenceforth be regarded as a unique swath and shall be assigned a unique File Source ID. Other swath segmentation approaches may be acceptable, with prior approval. Renaming schemes for split swaths are at the discretion of the data producer. The Processing Report shall include detailed information on swath segmentation sufficient to allow reconstruction of the original swaths if needed.
- 5.02.9** Each Swath shall be assigned a Unique File Source ID. The Point Source ID field for each point within each LAS swath file shall be set equal to the File Source ID prior to any processing of the data. See the LAS Specification.
- 5.02.10 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 (collected) order.
- 5.02.11** All collected swaths are to be delivered as part of the “Raw Data Deliverable” or arrangements need to be made by the contracting officer for storage, retrieval, and archiving of the “Raw Data Deliverable”. 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 outside of the buffered project area

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(aircraft turns, transit between the collection area and airport, transit between fill-in areas, etc.). These points may be permanently removed.

**5.03 American Society of Photogrammetry and Remote Sensing (ASPRS)/LAS Standard Classifications:** LiDAR point classes should be used in LiDAR point classification unless previously approved by the Contracting Officer. Any deviations from ASPRS classifications should be fully documented in project metadata. At a minimum Class 1, Class 2, Class 7, Class 9, and Class 11 (if applicable) should be populated. Class 8 and Class 10 should be populated when applicable if contour deliverables are a derived product.

<b><i>LIDAR Point Classes Classification Value (bits 0:4)</i></b>	<b><i>Meaning</i></b>
0	Created, never classified
1	Unclassified <sup>1</sup>
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Building
7	Low Point (noise)
8	Model Key-point (mass point)
9	Water
10	<i>Ignored Ground (Breakline Proximity)</i>
11	<i>Withheld (If the "Withheld" bit is not implemented the processing software or if client/end-user software is not capable of handling "withheld" bits)</i>
12	Overlap Points <sup>2</sup>
13-31	<i>Reserved for ASPRS Definition</i>

Withheld points are typically those points that were culled during preprocessing or post-processing. These points are typically not used in LiDAR processing. If Client end-user software is capable of handling withheld flags as defined in the ASPRS/LAS specifications, outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath (the geometrically usable center portion is typically ~90% of each swath) , and other points deemed unusable can be identified using the "Withheld" flag. It is important to verify this

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capability. Software used for analysis and visualization of final product deliverables may be different than software used to pre- and post-process LiDAR data. For example, at the present time, ESRI products for LAS to multipoint currently do not process withheld flags. If Client end-user software is not capable of handling withheld flags as defined in the ASPRS/LAS specifications, withheld points may be identified using Class =11. This applies primarily to points which are identified during preprocessing or through automated post-processing routines. “Noise points” subsequently identified during manual Classification and Quality Assurance/Quality Control (QA/QC) may be assigned the standard LAS classification value for “Noise” (Class =7), regardless of whether the noise is “low” or “high” relative to the ground surface.

**5.03.1** Overlap points are typically those points that were immediately culled during the merging of overlapping flight lines. This does not include geometrically unreliable points near the extreme edge of the swath which are considered withheld points as defined above. If **overlap points** are required to be differentiated by the Client, Contracting Officer, or Contractor, said points must be identified using a method that does not interfere with their classification, such as:

- Overlap points are tagged using Bit:0 of the User Data byte, as defined in the LAS specification. (SET=Overlap).
- Overlap points are classified using the Standard Class values + 16.
- Other techniques as agreed upon in advance.
- The technique utilized must be clearly described in the project metadata files.

If Client end-user software is capable of processing flags as defined in the ASPRS/LAS specifications, the ASPRS/LAS “Overlap” classification (Class=12) shall not be used. ALL points not identified as “Withheld” are to be classified. If Client end-user software is not capable of processing flags as defined in the ASPRS/LAS specifications, the “overlap” classification (Class 12) can be used with prior approval of the Contracting Officer.

Note: A standard bit setting for identification of overlap points has been planned for a future version of LAS.

**5.03.2 Positional Accuracy Validation:** The absolute and relative accuracy of the data, both horizontal and vertical, and relative to known control, shall be verified prior to classification and subsequent product development. This validation is obviously limited to the Fundamental Vertical Accuracy,

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measured in clear, open areas. A detailed report of this validation is a required deliverable.

**5.03.3 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 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 as required by the contract.

*Note: This requirement may be relaxed to accommodate collections in areas where the Contracting Officer agrees classification to be particularly difficult.*

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

**5.04 Tiles:** Shall be based on the North Carolina Base Modular unit and its subdivisions as dictated by tile size designated within the contract specifications.

**5.04.1 North Carolina Grid Panel Scheme** (see appendix D)

**5.04.2 Tile Names** shall use the “Naming Convention for Geospatial Data presented in the North Carolina Grid Panel Scheme.”

**5.04.3 Tile Size** must be an integer multiple of the cell size of raster deliverables.

**5.04.4 Tile** must be sized using the same **units** as the coordinate system of the data.

**5.04.5 Tiled Deliverables** shall conform to the tiling scheme, without added overlap.

**5.04.6 Tiled Edge-Match Deliverables** shall be seamlessly and without gaps in both the horizontal and vertical.

**5.04.7 Tile Size for All Deliverables** shall be the same. Raster, point, and vector data if said data is to be delivered in a tile format shall be the same as LiDAR data.

**6 HORIZONTAL AND VERTICAL QUALITY CONTROL:** If at all practical there should be an independent Quality Control Contractor employed for project review. North Carolina Geodetic Survey (NCGS) and North Carolina Center for Geographic Information and Analysis (NCCGIA) may be able to provide some guidance and assistance. Quality Control will be conducted by Quality Control Area (QC area). A QC area is that project area within a county boundary. If the project includes multiple counties or areas within multiple counties there will be a QC area for each county area, i.e., if it is a 4 county project then there will be 4 QC areas. If the project area is part of a county there is a QC area for that part of the county. A project buffer that includes an area within another county does not constitute an additional QC area. (see Appendix E)

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## 6.01 Independent Quality Control Checkpoints:

**6.01.1 Land Cover Categories:** The Quality Control Contractor will categorize all land into one of five major land cover categories representative of the project area (1) open terrain (e.g., bare-earth, sand, rock, plowed fields, short grass, golf courses); (2) high grass, weeds, and crops (e.g., hay, corn, wheat, tobacco); (3) brush lands and low trees; (4) fully forested; and (5) urban areas (vicinity of manmade structures, preferably high density). USGS National Land Cover Data 2006 ([www.mrlc.gov](http://www.mrlc.gov)) should be consulted as an initial reference before final determination is made and the latest ortho photography should be reviewed.

**6.01.2 Checkpoint Selection:** Quality Control Contractor will direct independent survey contractors to select 20 or more checkpoints, in each of the five land cover categories, except for forested areas where 40 checkpoints will be surveyed for each QC area. Each checkpoint should be on terrain that is flat or uniformly sloping within 5 meters in all directions (i.e., no breaklines within 5 meters of the checkpoint). Checkpoints clustered together will be rejected. The Quality Control Contractor will provide maps of land-cover categories, and the survey contractors will be provided with large-area polygons dispersed throughout each county within which the surveyors will select the checkpoints. Where possible, checkpoints should be interspersed throughout a QC area so that checkpoints will cover different flight lines. For example, if LiDAR flight lines are generally north-south, it is ideal for surveyors to survey in the vicinity of east-west roads in order to disperse checkpoints to cover different flight lines. The checkpoints in urban areas should be located, if possible, on clearly defined points expected to be visible on LiDAR intensity images, e.g., where a paint stripe on a road intersects with a curb line; recognizing that some points in urban areas may subsequently prove to be invisible on the LiDAR intensity image, those that are visible will be used to evaluate the LiDAR horizontal accuracy ( $Accuracy_x$ ) in addition to its vertical accuracy ( $Accuracy_z$ ).

**6.01.3 Checkpoint Surveys:** Quality Control Contractor will contract for independent surveys of all checkpoints to 5-cm Local Network accuracy according to NOAA Technical Memorandum NOS NGS-58, "Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)," Version 4.3, November 1997 (referred to as NGS-58). Static field procedures following the NGS-58 guidelines are preferred for establishing checkpoints. Alternatively, GPS Real Time Kinematic (RTK) field procedures using the North Carolina Real Time Network (RTN) or by establishing a temporary RTK base station may be used providing: (1) the temporary RTK base station is established on an existing NC HARN, NGS 3-D mark (that has published vertical value of 2<sup>nd</sup> order or higher) or a new NGS-58 mark established by NCGS; and (2) RTK can only be used in open areas, and each RTK point must be occupied twice on different days and at different times of the day. The purpose is to ensure different atmospheric conditions and significantly different satellite geometry. The difference between observations must not exceed 5 cm. Online Processing User Service (OPUS) can be used if the contractor obtains written approval from NC Geodetic Survey. Third-order or higher conventional

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surveys may be used to extend control from open areas (surveyed by GPS) to forested areas where GPS signals are blocked. Trigonometric leveling may be used in lieu of conventional leveling. To use trigonometric leveling, the field procedure used by the contractor must be approved by Quality Control Contractor. These checkpoints will be used for the official vertical accuracy assessments (Fundamental Vertical Accuracy and the Consolidated Vertical Accuracy) of the bare-earth LiDAR data after post processing.

- 6.01.4 Cluster Survey Points:** Additional survey measurement should be included where possible surrounding the control point being established for the vertical comparisons in vegetated areas. This will include both conventional methods and RTK. For RTK surveys, additional surrounding points within a few meters of the new control point should be established to help identify whether the LiDAR penetrated the vegetated surface. The same procedure can be utilized for conventional surveys. While the total station is set up, the survey instrument person could move a few meters in each direction to collect additional measurements. These additional cluster points will not be used for vertical accuracy assessments, but they will be used to evaluate artifacts and cleanliness.
- 6.01.5 Cross Section Surveys:** This survey will only be used when specified in the contract. Cross section surveys are be used when the data is collected along streams for flood mapping applications. The number of cross sections will depend on the water body, the surrounding terrain, and other local factors. A total of (to be determined by contract) cross sections of varying terrain will be measured. Ideally stream channels should be measured, but standard Airborne LiDAR will not include underwater measurements. If streams cannot be measured, undulating terrain or drainage ditches exceeding 3 meter width could be measured using RTK. Measurements could be taken at two meter intervals for 50 meters over undulating terrain. These cross section surveys will not be used for official vertical accuracy assessments, but they will be used to assess the bare-earth mass points to ensure that post-processing did not overly flatten stream channel geometry (stream banks) used for hydraulic modeling.
- 6.01.6 Documentation:** The survey company will mark each checkpoint with a 60d nail or larger. Photographs will be used to document the location, the land cover surrounding each stake, and the uniform slope of the terrain surrounding each stake. A full report will be required outlining the methodology of the data collection, the equipment used, software, full output of duplicate point comparisons, least squares adjustment, and any information pertinent to the survey. FGDC metadata will also be included with the final coordinates.
- 6.01.7 Orthometric Heights:** Geoid09 or current Geoid will be used to convert GPS ellipsoid heights into orthometric heights for each checkpoint, using NAVD 88, the specified vertical datum. Contact North Carolina Geodetic Survey for verification of current Geoid.
- 6.01.8 3-D Coordinate Files:** The PLS will provide Quality Control Contractor with Microsoft Excel 3-D point files (X-Y-Z values) by State Plane coordinates (U.S. survey feet) to 2 decimal places for the checkpoint surveys, cluster point

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surveys, and cross section surveys along with a code of the method used to derive the coordinate value (i.e., GPS or conventional survey).

**6.01.9 Security:** Quality Control Contractor will ensure that these 3-D coordinate files are secured and not made available outside of Quality Control Contractor and the Contracting Officer or his designee prior to receipt of the post-processed LiDAR data.

## 6.02 LiDAR Accuracy Assessment

**6.02.1 LiDAR Acquisition Plans:** The PLS in responsible charge of the elevation data collection will provide Quality Control Contractor with acquisition planning information, including, but not limited to, flight line directions, types of sensors, pulses per second, flying altitude above mean terrain, swath width, average point spacing, maximum positional dilution of precision (PDOP), maximum airborne GPS baselines, and sidelap percentage.

**6.02.2 LiDAR Acquisition Data:** Upon request, the PLS will provide Quality Control Contractor with actual data for each sensor on each day, to include daily calibration checks, flying altitude, average point spacing, maximum PDOP, maximum GPS baselines, etc., plus maps showing actual flight lines and swaths, by dates acquired and sensors (when multiple LiDAR systems are used). The daily Acquisition Report will be provided to the Quality Control Contractor by the end of the second business day following data acquisition to ensure data is actually processed in a timely manner.

**6.02.3 Bare Earth Data:** The PLS will post-process the LiDAR data to generate bare earth 3-D ASCII files or Triangulated Irregular Network (TIN) files.

**6.02.4 Interpolated Z-values:** When notified that the ASCII/TIN data are complete, 2-D (X-Y coordinates without Z-values) will be provided for all checkpoints per land cover category to the PLS. The PLS will immediately (within a few minutes) compute the interpolated LiDAR Z-values for the X-Y coordinates of the checkpoints and provide 3-D (X-Y-Z) files to Quality Control Contractor. Fewer than 20 checkpoints may be allowed in some land cover categories, if difficulty is encountered in finding certain vegetation groups.

**6.02.5 Checkpoint Elevation Discrepancies:** A spreadsheet with checkpoint elevation discrepancies (Z-values interpolated from LiDAR TIN minus Z-values from surveyed checkpoints) separated by land cover categories will be prepared. Draft values for Fundamental, Consolidated, and Supplemental vertical accuracies will be determined.

**6.02.6 Fundamental Vertical Accuracy Test:** Using only the checkpoints in open terrain, the RMSE will be computed of the bare-earth LiDAR dataset. If the  $RMSE_z$  value is equal to or less than 12.5 cm, then this test passes and the Fundamental Vertical Accuracy<sub>z</sub> = 1.9600 x  $RMSE_z$ ; proceed to step 6.02.7. If the  $RMSE_z$  is larger than the specified RMSE, there may be systematic errors or problem with the LiDAR sensor and/or parameters used for post-processing. All systematic errors need to be corrected and the dataset resubmitted for re-evaluation with additional checkpoints. Since there is no vegetation to be removed in post processing, there should be no excuse for the LiDAR dataset not performing to specifications in open terrain.

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**6.02.7 Supplemental Vertical Accuracy Test:** For each of the other four land cover categories, the quality control team will determine the 95th percentile error separately by land cover category. The 95th percentile equals the Supplemental Vertical Accuracy at the 95% confidence level by individual land cover category. Although there is no standard to be met, any individual land cover category with a 95th percentile error significantly larger than 1.6 ft (49.0 cm) is an indication that there may be a systematic problem in post-processing the LiDAR data for that type of land cover. Such information is valuable in trouble shooting should the Consolidated Vertical Accuracy test fail. See Section 1.03.5.2.14 95th Percentile and “Issue 37: Quality Control of Light Detection and ranging (LiDAR) Elevation Data in North Carolina for Phase II of the NCFMP” for guidance in figuring the 95<sup>th</sup> Percentile.

[http://www.ncfloodmaps.com/pubdocs/issue\\_papers/IP37-phaseII\\_lidar\\_qc.pdf](http://www.ncfloodmaps.com/pubdocs/issue_papers/IP37-phaseII_lidar_qc.pdf)

**6.02.8 Consolidated Vertical Accuracy Test:** Using all checkpoints in all five land cover categories combined, the quality control team will determine the 95th percentile error for the consolidated dataset. The 95th percentile equals the Consolidated Vertical Accuracy at the 95% confidence level for all land cover categories combined. If the Consolidated Vertical Accuracy is less than 1.6 ft (49.0 cm), then the dataset passes; if not, the dataset fails. For each dataset, the quality control team will also evaluate the error outliers that are larger than the 95th percentile. Outliers larger than 6.6 ft (2 meters) will be cause for investigation by the LiDAR provider to explain the large errors, but such outliers will not necessarily cause the dataset to fail. These will be evaluated on a case-by-case basis by the quality control team. The quality control team will document the magnitude of the errors that are larger than the 95th percentile.

**6.02.9 Vertical Accuracy Assessment and Reporting:** The Quality Control Team will prepare a LiDAR Accuracy Assessment Report that reports the following:

- Map with location of checkpoints, color-coded by land cover category
- Fundamental Vertical Accuracy at 95% confidence level in open terrain using  $RMSE_z \times 1.9600$ , compared with the 1.19 ft specification;
- Consolidated Vertical Accuracy at 95th percentile in all land cover categories combined, compared with the 1.61 ft specification;
- Supplemental Vertical Accuracy at 95th percentile, reported separately for open terrain, weeds and crops, scrub, forest, and built up areas, compared with the target of 1.61 ft.;
- Graphs showing the 95th percentile errors and RMSE errors, graphed separately for each of the five land cover categories;
- Magnitude of outliers larger than the 95th percentile, by land cover category;

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- Graph that illustrates the magnitude of the differences between the checkpoints and LiDAR data by specific land cover category, sorted from lowest to highest;
- Overall descriptive statistics to include RMSE, mean, median, skew, standard deviation, minimum and maximum errors, for each land cover category; and
- Histogram showing the frequency of checkpoint elevation differences, normally by 1 cm increments between the largest negative error and the largest positive error; this helps to visualize the outliers and proximity to a normal error distribution.

## 6.03 Error Assessment

**6.03.1 Assessments by Land Cover:** The causes for the data to not pass the accuracy criteria differ according to land-cover category. Typically, data in category "a" (open terrain) should pass the Fundamental Vertical Accuracy criteria unless there is a systematic problem; however, the daily calibration checks should confirm that the system performed well at the test site (on that same day with the same sensor), and the test site should be on bare terrain or short grass only. If the Consolidated Vertical Accuracy value is higher than the 1.6 ft (49.0 cm) standard, whereas the Fundamental Accuracy test passed the 1.2 ft (36.3 cm) standard, errors in post-processing need to be corrected, and the individual Supplemental Vertical Accuracy assessments should assist in trouble shooting. If Supplemental Vertical Accuracy tests are considerably higher than 1.6 ft (49.0 cm) for land cover categories "c" (scrub) or "d" (forests), the most probable causes are shortcomings in the vegetation-removal procedures. If the Supplemental Vertical Accuracy tests are considerably higher than 1.6 ft (49.0 cm) for land cover category "e" (urban areas), the most probable cause is a systematic problem with handling buildings or abnormal responses from asphalt.

**6.03.2 Assessments by Error Locations:** The Quality Control Team will evaluate the location of significant errors to see if they are consistent throughout the area and to determine where these errors are located within the flight line (e.g., near the beginning or end of swaths).

**6.03.3 Assessments by Dates/Sensors:** The Quality Control Team will evaluate the datasets to see if errors are distinguishable by dates or by individual sensors.

**6.03.4 Accuracy Assessment Report:** If the above assessments do not yield the probable source of systematic errors, the Quality Control Team will prepare an Accuracy Assessment Report indicating that the LiDAR data did not pass the accuracy criteria. This report will include the same type of information in task 6.02.9 above, but with a printout of z-value errors, sorted by elevations, without x/y coordinates. The report may identify polygons within which major errors are clustered, to assist in trouble-shooting. The report may recommend that

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quality control team spot check the elevations on several of the independent checkpoints that yielded the poorest results when compared with the interpolated LiDAR elevations, or the report may recommend that the LiDAR vendor assess the quality of individual components (airborne GPS, inertial measuring unit (IMU), and laser range systems) as well as the integrated system.

- 6.03.5 Airborne GPS Verification:** The PLS will examine GPS flight trajectories; verify the Positional Dilution of Precision (PDOP) and/or Vertical Dilution of Precision (VDOP); verify GPS satellite residuals; verify the satellite phase RMS; compare forward and reverse flight trajectories' combined separation; verify weighting adjustments when two or more differential base stations are used; verify the base station distance separation; verify position standard deviations; check satellite health; check geo-magnetic observations; verify that the correct vertical datum was used; and verify the correct application of the Geoid09 calculation of orthometric heights.
- 6.03.6 IMU Verification:** The PLS will review the Kalman filter, the measurement residual ratio (MRR), and the consecutive measurement rejections settings; confirm that the IMU was in "fine align" mode for the whole of the data set; check accelerometer drift and scale factor and gyro drift **and scale factor to ensure** that they are within specifications; compare GPS trajectory with re-computed IMU trajectory and investigate large discrepancies; and review IMU to lever arm parameter measurements and ensure that they are entered correctly in the proper reference system.
- 6.03.7 Laser Range Verification:** The PLS will review raw laser ranges; identify areas of high dropouts (no returns) and correlate them to justifiable features; review scanner mirror angles (galvanometers or micro-controller) reports; examine intensity images; and review system-generated error log sheets.
- 6.03.8 Total System Verification:** The PLS will review daily calibration checks and compare to system flight parameters; use CAD software to analyze flight lines and verify pitch, roll, and heading errors; check overlap for roll and scaling errors; check ground features for pitch (e.g., buildings, bridges); if water bodies exist, check scaling errors; compare cross flight data for altitude; review parameters if data were "corrected" or adjusted for pitch, roll, and heading errors; and verify vegetation removal procedure.
- 6.03.9 Systematic Error Corrections:** If systematic errors are found, the data will be reprocessed by the PLS, with clear written explanations provided to the quality control team. If no systematic errors are found, the process moves to Phase 4 discussed below.
- 6.03.10 Recalculation of Accuracy Statistics:** Using additional QC checkpoints, the PLS will interpolate the LiDAR dataset for the new checkpoints' 2-D (X-Y) coordinate values and provide 3-D (X-Y-Z) files for re-computation of Fundamental Vertical Accuracy and Consolidated Vertical Accuracy. The QC Contractor may be tasked to collect additional points from those points held in reserve.
- 6.03.11 LiDAR Accuracy Assessment Report:** If the new calculations from task 6.03.10 pass the accuracy criteria, the quality control team will prepare a

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LiDAR Accuracy Assessment Report indicating this fact. If the new calculations do not pass the accuracy criteria, a provisional Accuracy Assessment Report will document the new statistics and recommend alternatives (when pre-approved by Quality Control Contractor) listed in 6.04.

## **6.04 Final Resolution of Problems**

**6.04.1 Provisional LiDAR Accuracy Assessment Report:** As coordinated by client, the provisional Accuracy Assessment Report will document the accuracy assessments and recommend resolution to problems identified.

**6.04.2 LiDAR Vendor Checkpoints:** The PLS will provide the Quality Control Team with checkpoints used to validate the LiDAR adjustments, so that the Quality Control Team can determine the proximity of the LiDAR vendor checkpoints to the QC Contractor checkpoints, or perform independent surveys of the vendor's checkpoints.

**6.04.3 Elevation Contractor Control Points:** The PLS will provide the quality control team with control points and/or Least Squares Adjustments used to define the control points for the LiDAR processing. This will allow the quality control team to perform an independent analytical assessment of the vendor's control points to determine if there are any fundamental flaws or discrepancies in the control used for the project area. If the control points are inaccurate, the LiDAR vendor will need to resolve the control point(s) issue and reprocess the LiDAR data to fit the new control values. If the control points used are accurate, then 6.04.4 shall be implemented.

**6.04.4 Potential Resurveys of Quality Control Contractor Checkpoints:** The LiDAR vendor will be provided with 3-dimensional coordinates with supporting documentation and will be afforded the opportunity to independently survey and analyze the checkpoints used for the RMSE and 95th percentile calculations at the vendor's expense. If discrepancies are found with the coordinates, the Quality Control Team will rectify the problem and reassess the LiDAR data. If no discrepancies are found, the vendor shall comply with the results and establish procedures to correct the LiDAR data through reprocessing and/or reacquisition of the data.

**6.04.5 Potential Reacquisition of LiDAR:** The quality control team may decide that the LiDAR vendor be allowed to re-fly the area and acquire a new LiDAR dataset, perhaps with shorter GPS baselines, lower PDOP values, lower flying altitude, narrower swath widths, etc. This would normally be performed at the LiDAR firm's expense.

**6.04.6 Detailed Ground Surveys:** The PLS's firm may be offered the opportunity to perform extensive ground surveys of cross sections to satisfy the data needs for hydraulic modeling.

**6.05 Additional Quality Assessments:** *The PLS's firm may be tasked to provide additional deliverables and assessments: LiDAR intensity images, and shaded relief images of selected sample bare-earth mass point tiles.*

**6.05.1 Intensity Images:** In addition to the intensity images being used by the LiDAR vendor to assist in post-processing vegetation removal, the quality control team will request samples of intensity images at the urban area checkpoints so as to evaluate the horizontal accuracy of the LiDAR data, for

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comparison with the LiDAR vendor's own assessment of horizontal accuracy based on periodic calibration checks.

**6.05.2 Assessment of Cross Sections:** Cross sections of survey breakpoints along a stream channel will be compared to the corresponding cross section derived from the TIN. Using the survey cross sections, the horizontal component of the line derived from the survey points will be draped over the TIN. Interpolated elevation values will be generated from the intersection of the line with the vertices of the TIN and a new TIN cross section will result. Comparisons will be made between the surveyed cross section and the interpolated TIN Cross section. Differences will be measured at the breakpoints of the surveyed cross sections. Values greater than 49.0 cm will be evaluated on a case-by-case basis.

**6.05.3 Assessment of Edge Matching:** Edge matching will be tested with a variety of comparative methods. These methods will include a vector and/or a raster approach. If the data were flown with the same sensor, and the post processing procedures are consistent, very little change should be visible along seam edges. One method will be to compare the density of points within a given grid size (i.e. 20 ft.) along the tile boundaries. Significant discrepancies of point densities between adjacent tiles will flag further analysis. A second approach will be to build the TIN of each tile and compare the number of TIN triangles to the adjacent tile, or build a TIN of one tile including a 100 foot buffer of points from the adjacent TIN. Significant differences will again be flagged for review. A third approach would be to use a raster technique and create a TIN GRID. Visually the tile edges should be fairly seamless due to the interpolation of tile edges. Secondary to this, adjacent pixels along seam edges can be compared for elevation differences.

**6.05.4 Assessment of Superfluous Elevations:** Elevations will have a minimum and maximum value that should reflect the true range of the surface being measured. LiDAR at times can have errant elevation values that are well above or below the surface. Statistical analysis will be performed on the elevation data which will include: minimum and maximum elevation, standard deviation and the total number of points within a given class range (i.e. two-foot increments). Elevation values out of the norm, more than 20 feet from the next populous class will be flagged for review.

**6.06 Additional Duties of Quality Control Contractor.**

**6.06.1 Review LAS Point allocation**

**6.06.2 Review Flight Logs**

## 7 HYDRO-FLATTENING REQUIREMENTS:

*Note: Please refer to Appendix B for reference information on hydro-flattening.*

Hydro-flattening pertains only to the creation of derived DEMs. No manipulation of or changes to originally computed LiDAR point elevations are to be made. Breaklines may be used to help classify the point data.

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*Breaklines: North Carolina does not require any particular process or methodology be used for breakline collection, extraction, or integration. However, the following general guidelines must be adhered to:*

- *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 masspoints 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.*
- *These points are to be retained in the delivered LiDAR point dataset and shall be reclassified as “Ignored Ground” (class value = 10) so that they may be subsequently identified.*
- *Delivered data must be sufficient for the Client to effectively recreate the delivered DEMs using the LiDAR points and breaklines without significant further editing.*

## **7.01 Inland Ponds and Lakes:**

- 7.01.1** ~2-acre or greater surface area (~350’ diameter for a round pond) at the time of collection.
- 7.01.2** Flat and level water bodies (single elevation for every bank vertex defining a given water body).
- 7.01.3** The entire water surface edge must be at or below the immediately surrounding terrain.
- 7.01.4** Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, should be treated as rivers.

## **7.02 Inland Streams and Rivers:**

- 7.02.1** 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.
- 7.02.2** Flat and level bank-to-bank (perpendicular to the apparent flow centerline); gradient to follow the immediately surrounding terrain.
- 7.02.3** The entire water surface edge must be at or below the immediately surrounding terrain.
- 7.02.4** Streams channels should break at road crossings (culvert locations). These road fills should not be removed from DEM. However, streams and rivers should **not** break at elevated bridges. All elevated portions of Bridges should be

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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.

## **7.03 Non-Tidal Boundary Waters:**

**7.03.1** Represented only as an edge or edges within the project area; collection does not include the opposing shore.

**7.03.2** The entire water surface edge must be at or below the immediately surrounding terrain.

**7.03.3** 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.

## **7.04 Tidal Waters:**

**7.04.1** Water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any water body that is affected by tidal variations.

**7.04.2** Tidal variations over the course of a collection or between different collections will result in discontinuities along shorelines. This is considered normal and these “anomalies” should be retained. The final DEM should represent as much ground as the collected data permits.

**7.04.3** Variations in water surface elevation resulting in tidal variations during a collection should NOT be removed or adjusted, as this would require either the removal of valid, measured ground points or the introduction of unmeasured ground into the DEM. The client’s priority is on the ground surface, and accepts there may be occasional, unavoidable irregularities in water surface.

**7.04.3.1** Scientific research projects in coastal areas often have very specific requirements with regard to how tidal land-water boundaries are to be handled. For such projects, the requirements of the research will take precedence.

## **7.05 Single-Line Streams:**

**7.05.1** Breaklines for single-line streams shall be collected unless waved in writing by the Contracting Officer. If collected the following guidelines are required:

**7.05.1.1** All vertices along single-line stream breaklines are at or below the immediately surrounding terrain.

**7.05.1.2** 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 Appendix B, creates a non-traditional DEM that is not suitable for integration into the National Elevation Dataset (NED).

**7.05.1.3** All breaklines used to modify the surface are to be delivered to the client with the DEMs.

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- 7.06 Docks or Piers:** These guidelines apply only to docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.
- 7.07 Island Features:** The shoreline of islands within water bodies shall be captured as two-dimensional breaklines in coastal and/or tidally influenced areas and as three-dimensional breaklines in non-tidally influenced areas. Island features will be captured for features one-half acre in size or greater. These breaklines will be delivered as closed polygons with constant elevation.

An island within a Closed Water Body Feature will also have a “donut polygon” compiled in addition to an island polygon.

*Note: Breaklines: North Carolina does not require any particular process or methodology be used for breakline collection, extraction, or integration. However, the following general guidelines must be adhered to:*

- *Bare-earth LiDAR points that are in close proximity breaklines should be excluded from the DEM generation process. This is analogous to the removal of masspoints for the same reason in a traditional photogrammetrically compiled 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*
- *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.*

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

## 8 **TERRAIN MODELING SUPPLEMENTS:**

- 8.01 Road Features:** Both sides of paved road features, not including bridges and overpasses, shall be captured as edge-of-pavement breaklines. These features will be captured as three-dimensional breaklines.
- 8.02 Soft Features:** In areas where the LiDAR mass points are not sufficient to create a hydrologically correct DTM, soft features such as ridges, valleys, top of banks, etc., shall be captured as soft breaklines of varying elevations. These features will be captured as three-dimensional breaklines. Soft features may also include embankments.
- 8.03 Low Confidence Areas:** *Low Confidence Areas* are defined as vegetated areas that are considered obscured to the extent that adequate vertical data cannot be clearly determined to accurately define the DTM. These features shall be captured as two-dimensional closed polygon features. These features are for reference information indicating areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation.
- 8.04 Overpasses and Bridges:** Overpass and bridge features will be captured as three-dimensional breaklines; the breaklines will use the elevation of the edge of the driving surface as the z coordinate (rather than elevation of guard rails or other bridge surfaces). These breaklines will be segregated in some way from other breakline types.
- 8.05 Depressions** (sinks), natural or man-made, are **not** to be filled (as in hydro-conditioning and hydro-enforcement).
- 8.06 Water Bodies** (ponds and lakes), wide streams and rivers (“double-line”), and other non-tidal water bodies as defined in Section 6 are to be hydro-flattened within the DEM. Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are larger than ~2 acre in area (equivalent to a round pond ~350’ 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 Section 6 and Appendix B for detailed discussions of hydro-flattening.*

- 9 **DELIVERABLES:**** The Client 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. This

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Standard does not supersede any requirements imposed by State or Federal statute or regulation as to distribution such as the NC Public Records Law (NC GS 132).

Deliverables are to be forwarded to the Q/C team as they are completed.

- 9.01 Surveyors Certification:** All products prepared under the supervision of a North Carolina Professional Land Surveyor shall be accompanied with a report which will be certified and sealed by the surveyor in responsible charge in accordance with State Law and NC Board of Registration Administrative Code (See section 1.04).
- 9.02 Collection Report** detailing mission planning and flight logs.
- 9.03 Survey Report** detailing the collection of control and reference points used for calibration and QA/QC.
- 9.04 Processing Report** detailing calibration, classification, and product generation procedures including methodology used for breakline collection and hydro-flattening (*see Section 6 and Appendix B for more information on hydro-flattening*).
- 9.05 Quality Assurance /Quality Control (QA/QC) Reports** detailing the analysis, accuracy assessment and validation of:
- 9.05.1** The point data (absolute, within swath, and between swath)
  - 9.05.2** The bare-earth surface (absolute)
  - 9.05.3** Other optional deliverables as appropriate
- 9.06 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 (See 4.03).
- 9.07 Daily Calibration Report (See 4.03)**
- 9.08 Flight Plan Map (See 4.04)**
- 9.09 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 shapefile or geodatabase is preferred.
- 9.10 Metadata** will be attached to all appropriate deliverables; said metadata will be in FGDC-compliant metadata files.
- 9.10.1** 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.
  - 9.10.2** FGDC compliant metadata must pass the USGS metadata parser (“mp”) with no errors or warnings.
- 9.11 Raw Point Cloud**

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*Note: delivery of the Raw Point Cloud should be discussed by the contracting officer, arrangements should be made for storage, retrieval, and archiving of the “Raw Data Deliverable” if said data is to be held by a party other than the Client. This is a very large data set that is not readily usable by an end user.*

**9.11.1 All returns**, all collected points, fully calibrated and adjusted to ground, by swath shall be in **fully compliant LAS** v1.2 or v1.3, or current ASPRS LAS format standard. Point Record Format 1, 3, 4, or 5, (a newer LAS equivalent Point Record format may be substituted) .and shall include the following requirements if applicable. The Contracting Officer has final determination of LAS format to be used.

**9.11.2** LAS v1.3 or current ASPRS LAS format standard deliverables with waveform data are to use external “auxiliary” files with the extension “.wdp” for the storage of waveform packet data. See the LAS v1.3 or current ASPRS LAS specification for additional information.

**9.11.3** Georeference information is to be included in all LAS file headers.

**9.11.4** GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse.

**9.11.5** Intensity values (native radiometric resolution) are to be included.

**9.11.6** Requirements are one file per swath, one swath per file, and file size not to exceed 2GB, as described in 6.14.6.

## **9.12 Classified Point Cloud**

*Note: Delivery of a classified point cloud is a standard requirement for North Carolina LiDAR projects. Specific scientific research projects may be exempted from this requirement.*

**9.12.1 Fully compliant LAS** v1.2 or v1.3, Point Record Format 1, 3, 4, or 5, (a newer LAS equivalent Point Record format may be substituted)and shall include the following requirements if applicable.

**9.12.1.1** LAS v1.3 deliverables with waveform data are to use external “auxiliary” files with the extension “.wdp” for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.

**9.12.1.2 Georeference information** is to be included in LAS header.

**9.12.1.3 GPS times** are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse.

**9.12.1.4 Intensity values** (native radiometric resolution) are to be included.

**9.12.1.5 Tiled delivery**, without overlap (tiling scheme TBD), is to be included.

**9.12.1.6 Classification Scheme** (minimum) as follows:

Code	Description
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1	Processed, but unclassified
2	Bare-earth ground
7	Noise (low or high, manually identified, if needed)
8	Model Key Point (masspoint)
9	Water
10	Ignored Ground (Breakline Proximity)
11	Withheld (if the "Withheld" bit is not implemented in processing software)

*Note: Class 7, Noise, is included as an adjunct to the "Withheld" bit. All "noise points" are to be identified using one of these two methods.*

*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.*

**9.13 Bare Earth Surface (Raster DEM),** and shall include the following requirements if applicable.

*Note: Delivery of a bare-earth DEM is a standard requirement for LiDAR projects. Specific scientific research projects may be exempted from this requirement.*

**9.13.1 Cell Size** will be no greater than 3 meters or 10 feet, and no less than the design Nominal Pulse Spacing (NPS).

**9.13.2 Delivery** will be in an industry-standard, GIS-compatible, 32-bit floating point raster format (ERDAS .IMG preferred).

**9.13.3 Georeference Information** shall be included in each raster file.

**9.13.4 Tiled Delivery,** without overlap, is required.

**9.13.4.1** Each tile will include industry standard header information.

**9.13.5 DEM Tiles** will show no edge artifacts or mismatch. A quilted appearance in the overall project DEM surface, whether caused by differences in processing quality or character between tiles, swaths, lifts, or other non-natural divisions, will be cause for rejection of the entire DEM deliverable.

**9.13.6 Void Areas** (i.e., areas outside the project boundary but within the tiling scheme) shall be coded using a unique "NODATA" value. This value shall be identified in the appropriate location within the file header.

**9.13.7 Vertical Accuracy** of the bare earth surface will be assessed and reported in

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accordance with the guidelines developed by the NDEP and subsequently adopted by the ASPRS. The complete guidelines may be found in Section 1.5 of the Guidelines document. See:

[http://www.ndep.gov/NDEP\\_Elevation\\_Guidelines\\_Ver1\\_10May2004.pdf](http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf)

**9.13.7.1** Vertical accuracy requirements using the NDEP/ASPRS methodology are:

**9.13.7.1.1** FVA  $\leq$  24.5cm ACCz, 95% (12.5cm RMSEz) (see section 1.03.5.2.4 for RMSEz definition)

**9.13.7.1.2** CVA  $\leq$  36.3cm, 95th Percentile

**9.13.7.1.3** SVA  $\leq$  36.3cm, 95th Percentile

**9.13.7.2** All QA/QC analysis materials and results are to be delivered to the Client.

## **9.14 Breaklines**

*Note: Delivery of the breaklines used in hydro-flattening is a standard requirement. Specific scientific research projects may be exempted from this requirement. If hydro-flattening is achieved through other means, this section may not apply.*

**9.14.1** 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). Shapefile or geodatabase file formats are preferred.

**9.14.2** Each feature class or shapefile will include properly formatted and accurate georeference information in the standard location. All shapefiles must include the companion .prj file (projection).

**9.14.3** Breaklines must use the same coordinate reference system (horizontal and vertical) and units as the LiDAR point delivery.

**9.14.4** Breakline delivery may be as a continuous layer or in tiles, at the discretion of the data producer. Tiled deliveries must edge-match seamlessly, both horizontally and vertically.

## **10 COMMON DATA UPGRADES**

**10.01** Independent 3rd-Party QA/QC by another AE Contractor (encouraged)

**10.02** Higher Nominal Pulse Spacing (point density)

**10.03** Increased Vertical Accuracy

**10.04** Full Waveform collection and delivery

**10.05** Additional Environmental Constraints

**10.05.1.1** Tidal coordination, flood stages, crop/plant growth cycles, etc.

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**10.05.1.2** Shorelines corrected for tidal variations within a collection

- 10.06** Top-of Canopy (First-Return) Raster Surface (tiled). Raster representing the highest return within each cell is preferred.
- 10.07** Intensity Images (8-bit gray scale, tiled)
- 10.08** 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

- 10.09** Hydro-Enforced and/or Hydro-Conditioned DEMs
- 10.10** Breaklines (PolylineZ and PolygonZ) for single-line hydrographic features (narrow streams not collected as double-line, culverts, etc.), including appropriate integration into delivered DEMs.
- 10.11** Breaklines (PolylineZ and PolygonZ) for other features (TBD), including appropriate integration into delivered DEMs.
- 10.12** Extracted Buildings (PolygonZ): Footprints with maximum elevation and/or height above ground as an attribute.
- 10.13** Other products as defined by requirements and agreed upon in advance of funding commitment.

## **11** DERIVED PRODUCTS

- 11.01 Digital Terrain Models**
- 11.02 Triangulated Irregular Network (TIN).** A TIN is usable for small areas but quickly becomes unmanageable for larger areas. A Terrain Feature Class may be a better choice if the site is larger than  $\pm 150$  acres.
- 11.03 Hillshade Model**
- 11.04 Contours** shall be certified to meet or exceed National Map Accuracy Standards. Contours within low confidence areas shall be attributed as such and are not required to meet National Map Accuracy Standards. Contours must be delivered in the ArcGIS geodatabase or shapefiles format with separate feature classes for 1- and 2-foot contours. The feature classes will contain an elevation field and a contour

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type field with the specified domain. While contours should be moderately aesthetically pleasing to the layperson, this deliverable is not intended to develop high-quality cartographic contours. However, an acceptable level of smoothing should be established and approved and be consistent across all deliverables.

*Note: Relationship between National Standard for Spatial Data Accuracy (NSSDA) and National Map Accuracy Standard (NMAS) (vertical) NMAS (U.S. Bureau of the Budget, 1947) specifies the maximum allowable vertical tolerance to be one half the contour interval, at all contour intervals. If vertical error is normally distributed, the factor 1.6449 is applied to compute vertical accuracy at the 90% confidence level (Greenwalt and Schultz, 1968). Therefore, the Vertical Map Accuracy Standard (VMAS) based on NMAS is estimated by the following formula:*

$$VMAS = 1.6449 * RMSE_z$$

*The VMAS can be converted to Accuracy<sub>z</sub>, accuracy reported according to the NSSDA using equations from Appendix 3-A, Section 2:*

$$Accuracy_z = 1.9600/1.6449 * VMAS = 1.1916 * VMAS.$$

*Therefore, vertical accuracy reported according to the NSSDA is  $(1.1916)/2 * CI = 0.5958 * CI$ , where  $CI$  is the contour interval.*

**11.04.1** The contour domain contains the following eight values:

1. Intermediate
2. Supplementary
3. Depression
4. Index
5. Intermediate Obscured
6. Supplementary Obscured
7. Depression Obscured
8. Index Obscured

Index contours are defined below and will take precedence over the depression classification. Supplementary contours are only required for the Contour\_2FT feature class and are not required for the Contour\_1FT feature class. The contour type definitions listed below reference the USGS Digital Line Graph Standards (Part 7: Hypsography). <http://rockyweb.cr.usgs.gov/nmpstds/dlgstds.html>

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**11.04.1.1 Intermediate contours** (the three or four lines between adjacent index contours) are about half the line weight of index contours. They are normally continuous throughout a map, but may be dropped or joined with an index contour where the slope is steep and where there is insufficient space to show all of the intermediate lines.

**11.04.1.2 Supplementary contours** are used to portray important relief features that would otherwise not be shown by the index and intermediate contours (basic contours). They are normally added only in areas of low relief, but they may also be used in rugged terrain to emphasize features. Supplementary contours are shown as screened lines so that they are distinguishable from the basic contours, yet not unduly prominent on the published map.

**11.04.1.3 Depression contours** are closed contours that surround a basin or sink. They are shown by right-angle ticks placed on the contour lines, pointed inward (down slope).

**11.04.1.4 Fill contours** are a special type of depression contours, used to indicate an area that has been filled to support a road or railway grade.

**11.04.1.5 Index contours** are defined as every 5<sup>th</sup> contour line. For example, with the Contour\_2FT feature class, the first positive index contour would be 0 with the following index contours at 10, 20, and 30 feet, etc.

## 12 PRODUCT LIMITATIONS

**12.01 Points Designated as Bare Earth** should be reviewed with some skepticism in area of dense vegetation. These points could be more appropriately called last return because they are bare earth only if the pulse actually reaches the bare earth. In thick grass, brush, or dense leaf clutter the elevation will probably be above the actual ground elevation. Look for and pay attention to low confidence area designations.

**12.02 DEM, DTM, and TIN:** While LiDAR produces a very dense data set, the placement of points is random and not done intelligently. The terrain model will have some inconsistencies that would not typically be found in a terrain model generated from human, interactive techniques. This is due to points being chosen along terrain breaks rather than randomly near a terrain break. If precise data is required, dense post spacing is required or some supplemental ground or photogrammetric surveying can be included. DEM's tend to mask micro topography

# North Carolina Technical Specifications for LiDAR Base Mapping

within the cell boundaries. Depending on the use of the DEM this could produce some problems. For example, in orthophotography production, too large a cell in steep terrain can produce some wavering in linear features such as rail road tracks.

**12.03 Contours** at any interval can be generated from a digital terrain model but the reliability of the contours rapidly breaks down as the contour interval exceeds accuracy for the data set or for contours within low confidence areas. United States National Map Accuracy Standards, Vertical Accuracy, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error by more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale.

**12.04 Water and Asphalt Areas** tend to absorb some of the LiDAR signal giving an elevation below the surface.

## 13 APPENDICES

### Appendix A - Request for Qualifications (RFQ), Example:

#### REQUEST FOR QUALIFICATIONS

**1. General:** \_\_\_\_\_, herein after known as **the Organization** in this document, hereby request your written proposal for a contractual commitment to a digital LiDAR all return elevation mapping project. The project is to be divided into five phases (as shown in Section 2), and the response to the Request for Qualifications (RFQ). The primary deliverable for LIDAR Points, Waveform data and intensity horizontal data shall be North Carolina State Plane Coordinates, North American Datum (NAD) 1983 (NSRS 2007). Vertical data will be in NAVD 88. All data will be based on US Survey Foot unless otherwise approved and noted.

**2. Scope of Project:** This project will be divided into separate phases for the purposes of planning and funding; however, work may be done in several phases simultaneously.

**A. All Return LiDAR (collection phase):** LiDAR collection phase including pre-paneling for Project areas is required. Data Collection shall include all return point cloud data, intensity data, and waveform data. All LiDAR is to be flown according to the *Technical Specifications for LiDAR Data*, \_\_\_\_\_, *North Carolina Department of the Secretary of State, Land Records Management Division, here after known as State Standard*). The contractor must identify the LiDAR sensor by make, model and serial number to be used along with the specifications and certifications for the sensor per the *State Standard*. Data collection shall include reduction of the raw LiDAR information into LiDAR

# North Carolina Technical Specifications for LiDAR Base Mapping

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point data records including the combined information from GPS, IMU and laser pulse range data to produce X, Y, and Z point data.

**B. Ground Control:** The Contractor is to review the attached contract map to determine what horizontal / vertical control is required. North Carolina Geodetic Survey can provide information on existing government control monuments. If additional control is required, the Contractor is to indicate the location of the necessary additional control and describe how that control is to be established. The Contractor is to indicate on a proposed flight line map all of the control points planned for establishment or used to control this project. Previously flown LiDAR may be used in the preliminary check process by the contractor, but it is an unacceptable form of control.

**C. All Return LiDAR point cloud (processing phase):** The American Society of Photogrammetry and Remote Sensing (ASPRS) LAS Specification v 1.2, v 1.3 or later shall be used to process and store the point cloud into its respective designations.

**D. All Return Waveform data (processing phase)(optional):** The American Society of Photogrammetry and Remote Sensing (ASPRS) LAS Specification version 1.3 or later shall be used to process and store the wave form data into its respective format.

**E. All Return Intensity data (processing phase):** The American Society of Photogrammetry and Remote Sensing (ASPRS) LAS Specification v1.2 , v 1.3 or later shall be used to process and store the intensity data into its respective format.

**F. Production of LiDAR Base Maps:** Point cloud data and Intensity data shall be geo-segregated into the North Carolina paneling scheme. The LiDAR data is to be based on North Carolina NAD83 (NSRS 2007) US survey foot. A Map Inventory by Panel is attached as Appendix A. Map panels shall be named using the “North Carolina Land Records Management Program Naming convention for Geospatial data presented in the North Carolina Grid Panel Scheme”

## **G. Deliverable Product Specifications**

Two sets of digital LiDAR Data will be delivered on DVD's, on a portable hard-drive, or other portable media to the county for their contract area. All point data will be in ASPRS LAS v1.2, v 1.3 or later. Additional information will be included in accordance with *State Standards* and in a format approved by the contracting officer. DVD's and DVD containers will be labeled in accordance with *State Standards*.

In addition to the LiDAR data, any Derived Products that are specified in this proposal shall be included in the appropriate file format labeled with the same file name/number as the corresponding LiDAR.

# North Carolina Technical Specifications for LiDAR Base Mapping

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Metadata records, Metadata detailing the characteristics and quality of submitted point cloud data must be provided, including the version of this standard which the dataset uses. Metadata should make every effort to meet the more rigorous standards set forth in the Federal Metadata Content Standard, where feasible. Metadata must provide sufficient information to allow the user to determine if that data will meet the intended purpose, as well as telling the user how to access the data. Metadata must provide a process description summarizing collection parameters (flying height above ground, IMU type, ground GPS procedures, target spot spacing, kilohertz setting, and percent overlap) as well as process description highlighting steps toward delivered point cloud. Examples of metadata records may be found at <http://floodmaps.nc.gov/fmis/Download.aspx> (LiDAR Metadata).

The organization also requires a copy of the flight report, a list of existing monuments used for control, descriptions and data sheets for new control points established (it is recommended that these points be published in OPUS Data Base (<http://beta.ngs.noaa.gov/OPUS/>), and a signed and sealed surveyors report from the North Carolina Professional Land Surveyor (PLS) in responsible charge.

## H. Ownership of Materials

All materials produced as a result of this project including but not limited to LAS point data, bare earth data set, intensity data, control points, terrain and elevation models shall become property of the Organization. The Organization may request that the Contractor store these materials at the Contractor's facility at no charge; however, any and all materials shall be returned to the Organization upon written request.

**3. Organization Contract Map:** A copy of the Organization Contract Maps are attached as Appendix A and will become a part of the final contract. These contract maps depict the boundaries of the maps to be delivered and the panel layout and panel size to be used.

## 4. Desired Timetable:

A. LiDAR Data collection covering the County will be flown and completed prior to dd, mm, yyyy. New and existing horizontal and vertical ground control shall be established prior to or during LiDAR collection. Exporting of the raw data from the airplane collection system is considered part of collection.

B. Processing the raw data into the ASPRS LAS format is to begin as soon as the additional horizontal ground control (if required) has been established and approved by the Contracting Officers.

C. All LiDAR base maps are to be completed and delivered to the Organization by dd, mm, yyyy. The project is not considered complete until all reports and deliverables have been review and accepted the contracting officer.

**5. Conformance to Specifications:** All work performed by the Contractor under any agreement resulting from selection for this project shall be in strict conformance with the

# North Carolina Technical Specifications for LiDAR Base Mapping

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*State Standards* attached to this RFQ unless otherwise noted. Any modifications to the LiDAR specifications or other terms of the Agreement shall be permitted only upon written request by the Contractor, stating justifications thereof, and with written approval by the Organization. There will be visual quality control checks and ground- truthing done in accordance with *State Standard*.

**6. Technical Proposals:** Outline of Proposal – The Contractor’s technical proposal should be organized so that the outline of the proposal generally follows the format of the *State Standards*. The proposal should cover the approach and the methods the Contractor intends to use in carrying out the project. The Contractor must indicate on a copy of the Organization’s Contract Map the control points that will be paneled and all flight lines to be flown, and include this map as part of the proposal.

Responsibility for Proposal Costs - The vendor shall be responsible for all costs incurred in proposal preparation and submission.

Bonding – A letter from a reputable bonding company verifying that the firm can be bonded for this project must be submitted with the proposal. A Performance Bond, a surety bond of 100 percent (100%) of the amount of the proposal, shall be required for the faithful performance of the contract and to indemnify the Organization against loss. The Contractor is to also furnish a payment bond to insure payment for all materials and subcontracting. The premiums are to be paid by the Contractor. The surety must be a substantial surety company satisfactory to the Organization, authorized by law to do business in the State of North Carolina and endorsed by a local representative of such surety company. All performance and payment bonds shall name \_\_\_\_\_ as obligee. Certified proof that the bond has been issued by an approved bonding firm must be presented.

Equipment – A list of all equipment that will be used in this project is to be included in the technical proposal.

Binding – The Contractor shall be bound by its proposal for a term of ninety (90) calendar days from the due date of the proposals. A Contractor may withdraw a proposal by written request prior to the date and time of the proposal opening.

Present Workload – The Contractor shall include in the technical proposal a complete tabulation of its currently held projects. Each such project shall be identified by name and be defined as to size, required period of performance, equipment and personnel assigned to that project as well as the completion deadline.

**7. Subcontracting:** The Organization desire to contract with a firm that can perform all primary functions of the Digital LiDAR project. Subcontracting any portion of project is acceptable but must be indicated in the proposal. Personnel and work location of said personnel shall be disclosed.

# North Carolina Technical Specifications for LiDAR Base Mapping

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**8. Qualifications:** The Organization desires to contract with a firm that has experience performing LiDAR Collection, airborne GPS control and LiDAR Base mapping production with its own staff and equipment. The Contractor shall include in this proposal a description of at least two regional LiDAR projects that have been successfully completed with aircraft and equipment owned by the contractor and staff directly employed by the contractor. If the proposing firm is planning to use subcontractors in fulfilling any phase of this project, the subcontractor shall be identified by name, credentials must be clearly defined and any equipment utilized by said subcontractor must be indicated. All work location shall be disclosed for the contractor and subcontractors. Any production work that is proposed to be performed outside of the United States or its Territories shall require a waiver by the Contracting Official.

A list of key staff members who are assigned to this project must be provided. The information shall include resume, professional credentials, certificates, licenses and level of qualifications that are necessary to perform this project. This includes the North Carolina Professional Surveyor that is designated to be in responsible charge of the project.

**9. Disqualifications:** The Organization reserves the right to disqualify any company upon discovery by the Organization of any convincing evidence of collusion with intent to defraud or to commit any other illegal practices on the part of the company. Failure to comply with applicable state laws concerning insurance or bonding may also be grounds for disqualification. The Organization reserves the right to reject any and all proposals.

**10. Award of Contract:** The award will be made to the Contractor who submits the proposal which is in the best interest of the organization. Such evaluations will include the relevant experience of the contractor, the capability of the contractor, the cost of the project and other factors deemed by the organization to be in the best interest of the organization. The organization reserves the right to reject any or all proposals at its sole discretion or to waive any specific irregularities or formalities in order to accept a proposal deemed to be in the best interest of the organization.

**11. Inquiries:** Questions concerning this RFQ should be directed to:

[Contact name and title, address, phone, fax, email]

All correspondence and questions should be in writing and all responses should be in writing. Any questions that the Organization feel are pertinent to all proposers will be mailed along with their corresponding answers as an addendum to the RFQ. Fax and email messages will be treated as written questions.

**12. Submission of Proposals:** Final written proposals must be submitted to \_\_\_\_\_ . Proposals must be received no later than 4:00 p.m. (local time) on \_\_\_\_\_. Two hard copies with original signatures and one PDF digital copy of the original must be submitted. Late proposals will not be considered.

# North Carolina Technical Specifications for LiDAR Base Mapping

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**13. Save Harmless:** The successful Contractor shall indemnify and save harmless the parties of the Organization from suits, actions, damages, and cost of every name and description resulting from work under this contract during its prosecution and suits brought against any parties of the Organization for or on account of the use of patented appliances, products, or processes, or the infringement of any patent, trademark, copyright, or alleged negligence on the part of the Contractor. At the time of contracting, the successful vendor must supply evidence of insurance to cover liability for mishaps of the vendor.

**14. Taxes:**

A. Federal Taxes – \_\_\_\_\_ County, is exempt from Federal Excise Taxes and Transportation Taxes. The County will issue exemption certificates only upon request of the Contractor. The County will not guarantee any Federal Tax refunds to the Contractor.

B. State Taxes – \_\_\_\_\_ County is liable for North Carolina Sales and Use Taxes; however, this item shall not be shown on the proposal but shall be added to invoices as a separate item.

**15. Payment:** Payment of the final invoice and retainage shall be made within 30 days after, in the judgment of the Organization’s representatives, the Contractor has completely delivered all materials or performed all services in accordance with the specifications and the terms of the contract. Payment will be allowed for work in progress. The Contractor must show that the portion of work included in the invoice is completed. A retainage of ten percent (10%) will be withheld from each invoice until all of the deliverable products are delivered to and formally accepted by the Organization as complete, satisfactory, and meeting all applicable specifications and standards. The contractor shall warrant the project from defects not meeting best management practices for one year.

**16. Liquidated Damages:** The Organization and the Contractor shall mutually agree on incremental delivery dates for the deliverables prior to signing the final contract. This delivery schedule shall be included in the contract. Should the contractor fail to meet the delivery schedule of the contract, a liquidation damage of one hundred dollars per calendar day (\$100.00/calendar day) will be imposed until delivery is made unless written authorization of extension is granted by all parties of the Organization. Request for extensions must be submitted in writing by the Contractor with full explanation as to reasoning for request of extension.

**17. Submission of Proposal:** Proposals must be on the standard forms furnished by the Organization. The Technical Proposal is required. Proposals must be placed in a sealed envelope plainly marked to indicate its contents without being opened. All packages shall be clearly labeled on the outside with the following notice:

# North Carolina Technical Specifications for LiDAR Base Mapping

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“PROPOSAL FOR \_\_\_\_\_ COUNTY DIGITAL LiDAR MAPPING”

**18. Signing Proposals:** The Organization will prepare contracts for the successful Contractor using the name exactly as it appears in the proposal. Therefore, it is absolutely necessary that proposers sign the proposal using their correct and complete legal names.

**19. Other instructions:**

A. North Carolina law does not permit the award of contracts when proposals contain escalation clauses unless (1) the escalation clause incorporates a maximum figure for escalation, or (2) the escalation is computed at a fixed rate per period of time and the periods of time have a cut-off date so that there is a computable maximum escalation figure.

B. The Organization shall have a period of thirty (30) days after the opening of the proposals in which to award the contract.

C. The Organization expressly reserves the right to reject any or all proposals, to waive any informality or irregularities in the proposals received, and to accept the proposal which best serves the interests of the Organization (according to the judgment of the Organization).

D. The award will be made to the Contractor who submits the proposal which is in the best interest of the Organization. Such evaluations will include the directly related experience of the Contractor, the capability of the Contractor, the cost of the project, time frame to complete the project and completeness of the proposed program as well as other factors deemed by the Organization to be in the best interest of the Organization.

E. Proposals will be opened at 4:00 p.m. on \_\_\_\_\_ by the \_\_\_\_\_. Proposals received which are not in compliance with the above instructions will be considered to be non-responsive and will not be evaluated for possible award.

**20. Project Schedule**

A. RFQ sent to Contractors (\_\_\_\_\_)

B. Written Questions due by (\_\_\_\_\_)

C. Proposals due (\_\_\_\_\_)

D. Contractor Interviews (if necessary) (\_\_\_\_\_)

E. Contractor Selection (\_\_\_\_\_)

# North Carolina Technical Specifications for LiDAR Base Mapping

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F. Project Completion (\_\_\_\_\_)

## Optional Items:

Option # 1 -\_\_\_\_\_. See previous option maps for area size for entire project area and for individual county sizes.

It is distinctly understood that the County Board of Commissioners reserves the right to reject any or all proposals.

## Alternate Proposal

The Organization desires to obtain LiDAR data at the same scales, pixel resolutions and accuracies as described in the primary RFQ, but welcomes the opportunity to discuss methodology which may include different or innovative procedures and equipment. This proposal should include a step-by-step narrative of the methodologies and equipment to be utilized as well as the Contractor's experience providing similar deliverables.

## Appendix B: HYDRO-FLATTENING REFERENCE

The subject of modifications to LiDAR-based Digital Elevation Models (DEM) 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 National Elevation Dataset (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**” is also new, coined for this document and to convey our specific needs. It is not, at this time, a known or accepted term across the industry. It is our hope that its use and acceptance will expand beyond the USGS with the assistance of other industry leaders.

Hydro-flattening of DEMs is 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. The USGS does not require the use of any specific technique.

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 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

# North Carolina Technical Specifications for LiDAR Base Mapping

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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, this process could create 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 National Elevation Dataset (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, above-ground structures that have been added to the landscape.

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

For years, raster DEMs, have been created from a Digital Surface Model (DSM) of masspoints and breaklines, which in turn were created through photogrammetric

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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, the USGS National Geospatial Program (NGP) requires that all DEMs delivered have their inland water bodies flattened. This does not imply that a complete network of topologically correct hydrologic breaklines be developed for every dataset; only those breaklines necessary to ensure that the conditions defined in Section 7 exist in the final DEM.

USGS NGP LiDAR Guidelines and Base Specification Version 13 – ILMF 2010

[http://lidar.cr.usgs.gov/USGS-NGP%20Lidar%20Guidelines%20and%20Base%20Specification%20v13\(ILMF\).pdf](http://lidar.cr.usgs.gov/USGS-NGP%20Lidar%20Guidelines%20and%20Base%20Specification%20v13(ILMF).pdf)

## Appendix C: Naming Convention for Geospatial Data Presented in the North Carolina Grid Panel Scheme see

<http://www.secretary.state.nc.us/land/ThePage.aspx> and download NC Base Mapping file naming convention.pdf

## Appendix D: Issue Papers [http://www.ncfloodmaps.com/issue\\_papers.htm](http://www.ncfloodmaps.com/issue_papers.htm)

## Appendix E: Quality Control of Light Detection and Ranging (LiDAR) Elevation Data in North Carolina (Background)

Reference Appendix A, *Guidance for Aerial Mapping and Surveying*, of FEMA's Guidelines and Specifications for Flood Hazard Mapping Partners at [www.fema.gov/mit/tsd/dl\\_cgs.htm](http://www.fema.gov/mit/tsd/dl_cgs.htm), and the National Standard for Spatial Data Accuracy (NSSDA) which specifies that accuracy of geospatial data be reported in ground distances at the 95% confidence level. The requirements for digital elevation data for flood insurance studies should be determined early in the process. Typically, for hydraulic modeling, FEMA specifies that elevation data equivalent to 4' contours ( $RMSE_z = 1.2$  ft (37 cm);  $Accuracy_z = 2.4$  ft (72.5 cm) at 95% confidence level) are appropriate for rolling to hilly terrain, and elevation data equivalent to 2' contours ( $RMSE_z = 0.6$  ft (18.5 cm);  $Accuracy_z = 1.2$  ft (36.3 cm) at 95% confidence level) are appropriate for flat terrain. FEMA encourages its own Project Officers, as well as

## North Carolina Technical Specifications for LiDAR Base Mapping

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Cooperating Technical Partners and States, to establish practical accuracy requirements for digital elevation datasets consistent with technical requirements and funds available.

For Phase I of the North Carolina Floodplain Mapping Program (NCFMP) initiated in 2000, the state specified a vertical RMSE ( $RMSE_z$ ) of 20 cm for coastal counties and  $RMSE_z$  of 25 cm for inland counties, computed after deletion of the worst 5% of the checkpoints. This is equivalent to vertical accuracies ( $Accuracy_z$ ) of 1.3 ft (39.2 cm) and 1.6 ft (49.0 cm), respectively, at the 95% confidence level, except that all accuracy assessments for Phase I were based on the best 95% of the checkpoints rather than the entire population of checkpoints. In 2000, the state had no better way to accommodate the fact that up to 5% of the checkpoints might not follow a normal error distribution required for the RMSE process to be applicable. There were no published alternatives at the time, other than accepting the fact that, by utilizing 100% of the checkpoints, even a single outlier could totally skew the RMSE calculations and accuracy assessments derived there from. Since the majority of Phase I LiDAR datasets had error distributions that did not follow a normal distribution, this demonstrated the validity of not using RMSE calculations for all 100% of the checkpoints because this would have unduly skewed the accuracy statistics.

In 2002, the National Digital Elevation Program (NDEP) established draft guidelines that specifically address LiDAR and the fact that the RMSE process is inappropriate for many land cover categories except for open terrain where there are no valid reasons why errors should not follow a normal error distribution. Version 1.0 of the final NDEP guidelines were published on May 10, 2004 (see [http://www.ndep.gov/NDEP\\_Elevation\\_Guidelines\\_Ver1\\_10May2004.pdf](http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf)) entitled: "*Guidelines for Digital Elevation Data.*" The NDEP guidelines specify Fundamental Vertical Accuracy at the 95% confidence level, computed by multiplying the  $RMSE_z$  by 1.9600, for open terrain only; this establishes the fundamental accuracy of the LiDAR sensor in open terrain. Additionally, the NDEP establishes both Supplemental Vertical Accuracy for other individual land cover categories, and Consolidated Vertical Accuracy in all land cover categories combined, using the 95th percentile errors to determine vertical accuracy at the 95% confidence level. This allows 5% of the checkpoint errors to exceed the established standard for  $Accuracy_z$ . The Supplemental Vertical Accuracy establishes the vertical accuracy in land cover categories, other than open terrain, where there may be legitimate reasons why errors do not follow a normal distribution; this determines how well the sensor performed, as well as the effectiveness of the post-processing used to establish "bare earth" elevations. The Consolidated Vertical Accuracy does the same for all combined land cover categories representative of the area being mapped.

For Phase II of the NCFMP, the state has specified Fundamental Vertical Accuracy of 1.2 ft (36.3 cm) in open terrain, and Consolidated Vertical Accuracy of 1.6 ft (49.0 cm) in all land cover categories combined, including open terrain, weeds and crops, scrub, forests, and urban terrain (built-up areas). The state has also specified horizontal (radial) accuracy ( $Accuracy_r$ ) of 5.68 ft (1.73 m) at the 95% confidence level, which is equivalent

# North Carolina Technical Specifications for LiDAR Base Mapping

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to a horizontal (radial) RMSE ( $RMSE_r$ ) of 3.28 ft (1 meter). These same specifications pertain to Phase III.

## Appendix F: Example of a LiDAR Metadata record

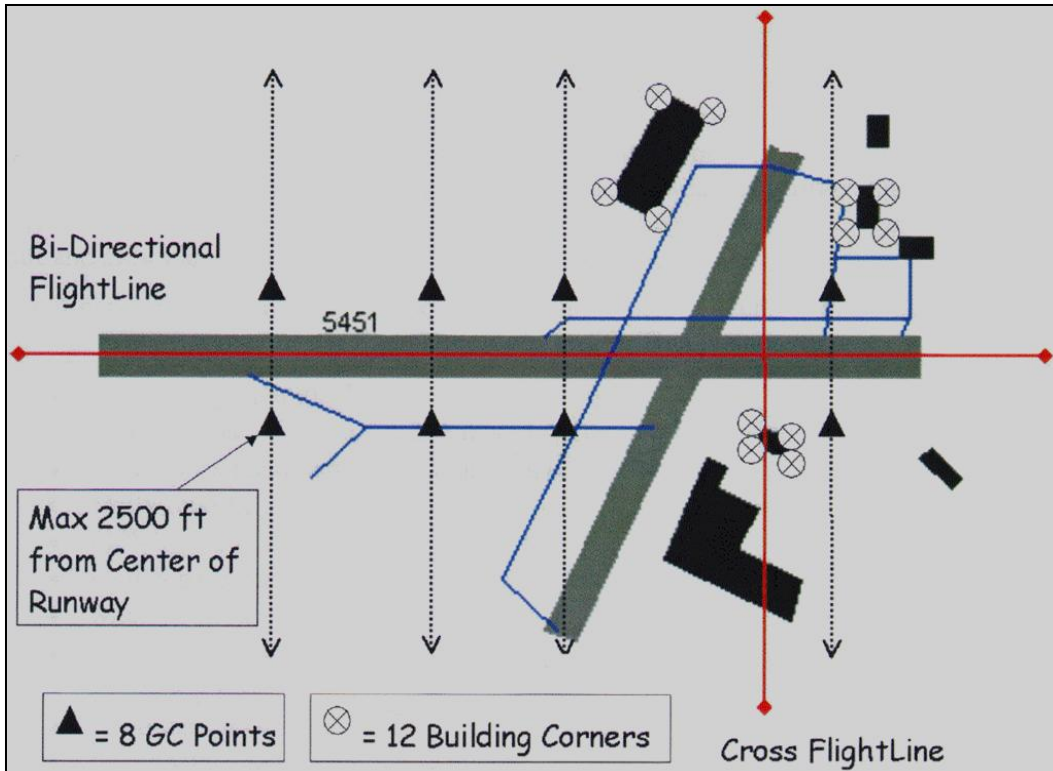
See: <http://www.oregongeology.org/sub/lidar/metadata/metadata-lidar.htm>

## Appendix G: Daily Calibration Survey / Boresight Calibration

What's a boresight?

- GPS antenna, IMU center of mass, and the LiDAR detector are all at physically different locations
- We do not really care what the position of the antenna or attitude of the IMU is – rather, we use these to calculate a precise offset to determine the exact location and orientation of the LiDAR detector
- Shock of landing and other environmental changes can shift the position of the instruments enough to upset data.
- This test is performed for each flight mission
- Removes systematic errors
  - Flight-to-flight variations on instrument mounting
  - Environmentally induced changes
- Performing a kinematic GPS survey on a roadway within the collection area is a reliable check
  - Validate the vertical for a feature with first returns on an unobstructed surface
  - Apply any vertical correction as necessary (a “z-bump”)

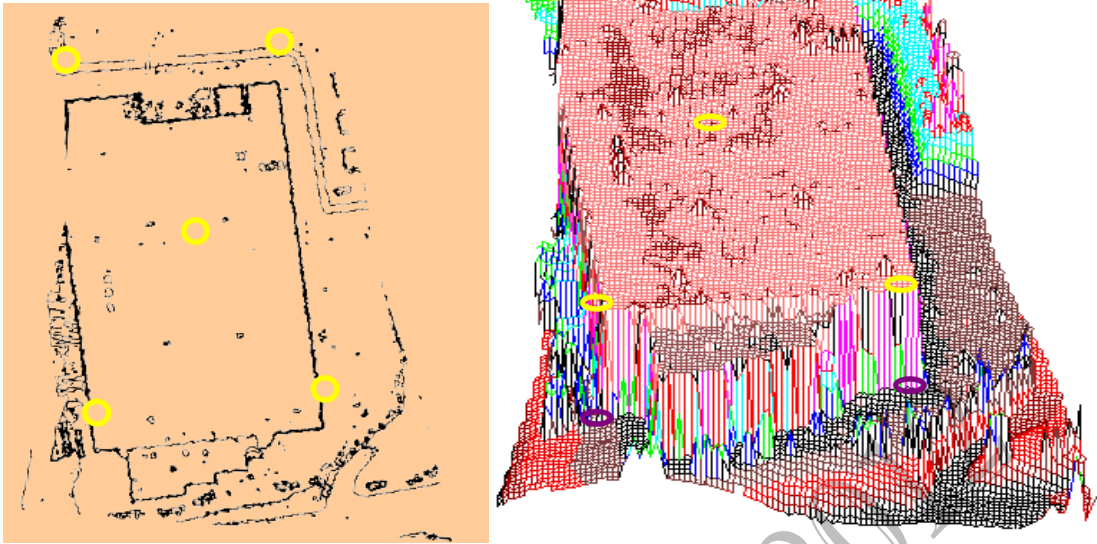
# North Carolina Technical Specifications for LiDAR Base Mapping



## The Importance of daily Calibration

- Control points on a building and other regularly shaped surfaces are acquired
- Results of calibration flights compared to control points to correct for:
  - edge curl
  - pitch
  - timing issues (GPS, IMU)
  - other system biases
- If the instrument is not “dialed-in” for each mission, data from successive lifts will not match!!

# North Carolina Technical Specifications for LiDAR Base Mapping



## Appendix H: ASPRS Guidelines, Vertical Accuracy Reporting for LiDAR Data,

[http://www.asprs.org/a/society/committees/lidar/Downloads/Vertical\\_Accuracy\\_Reporting\\_for\\_Lidar\\_Data.pdf](http://www.asprs.org/a/society/committees/lidar/Downloads/Vertical_Accuracy_Reporting_for_Lidar_Data.pdf)

## Appendix I: Affirmation of Vertical Datum for Surveying and Mapping Activities

Federal Register / Vol. 58, No. 120 / Thursday, June 24, 1993 / Notices 34245

[Docket No. 930650-3150]

### Affirmation of Vertical Datum for Surveying and Mapping Activities

**SUBAGENCY:** National Ocean Service, Coast & Geodetic Survey. National Oceanic and Atmospheric Administration, DOC.

**ACTION:** Notice.

**SUMMARY:** This Notice announces a decision by the Federal Geodetic Control Subcommittee (FGCS) to affirm the North American Vertical Datum of 1988 (NAVD 88) as the official civilian vertical datum for surveying and mapping activities in the United States performed or financed by the Federal Government. and to the extent practicable, legally allowable, and feasible, require that all Federal agencies using or producing vertical height information undertake an orderly transition to NAVD 88.

# North Carolina Technical Specifications for LiDAR Base Mapping

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**FOR FURTHER INFORMATION CONTACT.** Mr. James & Stem, N/CG1x4, SSMC3, Station 9357, National Geodetic Survey. NOAA, Silver Spring, Maryland 20910; telephone: 301-713-3230.

**SUPPLEMENTARY INFORMATION** The Coast and Geodetic Survey (C&GS), National Geodetic Survey (NGS), has completed the general adjustment portion of the NAVD 88 project, which includes approximately 80 percent of the previously published bench marks in the NGS data base. The remaining "posted" bench marks which comprise approximately 20 percent of the total will be published by October 1993. Regions of significant crustal motion will be analyzed and published as resources allow. NAVD 88 supersedes the National Geodetic Vertical Datum of 1929 (NGVD 29) which was the former official height reference (vertical datum) for the United States. NAVD 88 provides a modern, improved vertical datum for the United States, Canada, and Mexico. The NAVD 88 heights are the result of a mathematical least squares general adjustment of the vertical control portion of the National Geodetic Reference System and include 80,000 km of now U.S. Leveling observations undertaken specifically for this project. NAVD 88 height information in paper or digital form is available from the National Geodetic Information Branch, N/CG174, SSMC3, Station 9202, National Geodetic Survey. NOAA, Silver Spring, Maryland, 20910; telephone: 301-713-3242.

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