



Lidar Acquisition Specifications for Forestry Applications

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Background

In order to effectively support many natural resource management decisions, the USDA Forest Service (USFS) requires information about the vertical and horizontal structure of vegetation and the underlying terrain. Light Detection and Ranging (lidar) provides unique three dimensional (3-D) information that simultaneously measures the ground surface and forest canopy structure across acquisition areas in a comprehensive and accurate way that no other remote sensing technology currently offers. Based on the capability to provide detailed 3-D information, lidar is being used more frequently in forestry applications (e.g., forest inventories, engineering operations, and habitat modeling).

The primary obstacle to acquiring new lidar data is the cost. To mitigate this, many federal government agencies have formed consortia with state and local government, as well as academic and research institutions to share acquisition costs. The most notable large scale effort is the 3D Elevation Program (3DEP) spearheaded by the United States Geological Survey (USGS). The USGS has collaborated with other federal agencies to initiate 3DEP in response to the growing needs for high-quality topographic data and other lidar derivatives.

The primary goal of 3DEP is to systematically collect lidar for high-quality topographic information in an eight year period over the conterminous United States, Hawaii, and the U.S. territories (USGS 3DEP website: <http://nationalmap.gov/3DEP/>). The USGS Lidar Base Specification document (<http://pubs.usgs.gov/tm/11b4/>) details four quality levels (QL) that define minimum acceptable parameters of the lidar data and are intended to help provide consistency among partner-funded lidar collections, especially for 3DEP and the National Elevation Dataset (NED). As USFS budgets erode and more agencies are interested in partnering to acquire lidar, it only makes sense to view forestry acquisition specifications through the 3DEP defined QL's (e.g., table 1).

Table 1. Adapted from 3DEP specifications, this table shows the four quality levels along with the associated Aggregate Nominal Pulse Density and the associated non-vegetated vertical accuracy at the 95-percent confidence level in centimeters. For forestry applications and vegetation characterization, QL1 is generally recommended. Please refer to the USGS Lidar Base Specification document (<http://pubs.usgs.gov/tm/11b4/>) for more information.

<u>Quality Level (QL)</u>	<u>Aggregate Nominal Pulse Density (ANPD) (pulses/m²)</u>	<u>Non-vegetated vertical accuracy at 95-percent confidence level (cm)</u>
QL0	≥ 8.0	≤ 9.8
QL1	≥ 8.0	≤ 19.6
QL2	≥ 2.0	≤ 19.6
QL3	≥ 0.5	≤ 39.2

Partnership funding for 3DEP lidar acquisition projects is available through the USGS Broad Agency Announcement (BAA) (<http://nationalmap.gov/3DEP/>). Interested parties can contribute funds toward a USGS lidar acquisition activity via the Geospatial Products and Services Contracts (GPSC), or alternatively, they can request 3DEP funds go toward a lidar data acquisition activity when the USFS is the acquiring authority. However, while partnerships provide a way to stretch agency dollars, we need to remain cognizant that partnering may necessitate compromising on acquisition specifications and could in turn diminish the value of the resulting data products. Therefore, it is important that USFS users are abreast of the appropriate acquisition specifications for their desired applications. To support USFS users with this, we address the following three primary objectives in this document:

- Review recommended lidar specifications for forestry applications;
- Describe products that are typically delivered by the vendor and those that can be created from lidar data; and
- Provide an example Statement of Work from a recent USFS lidar acquisition ([Appendix](#))

Recommended Lidar Specifications

Acquisition specifications are heavily influenced by the intended application (e.g., topographic analysis vs. forest inventories). Therefore, specifications should be developed after careful planning and evaluation of project needs, while considering budgets, partnerships, and intended use of the lidar data. As such, acquisition planning is challenging and often entails tradeoffs. However, loosening certain specifications may impact the utility of the lidar data and should be carefully considered. This section highlights recommended specifications for forestry applications and considers the potential impact of specific parameters to the final products.

The four 3DEP quality levels provide consistency among the USGS and partners to acquire and use lidar for 3DEP applications (table 1). It should be noted that the 3DEP QL's are specifically designed to support high-quality *topographic* data, not specifically *vegetation* characterization. As such, the minimum acceptable 3DEP QL for vegetation characterization is QL2 (ANPD of 2 pulses/m²). However, to accurately quantify tree heights, forest structure, and forest inventory parameters using lidar, the research community generally agrees that at least an ANPD of 4 pulses/m² is necessary (Reutebuch & McGaughey, 2008). For this reason, in most cases, QL1 (ANPD of 8 pulses/m²) provides the ideal specifications for forestry related acquisitions.

In addition to pulse density, other notable acquisition specifications that are recommended for lidar acquisitions focused on forestry applications include: a narrow beam divergence, a scan angle of $\leq 13^\circ$, 50% side lap, opposing flight lines and a higher pulse frequency. Narrow beam divergence settings provide more accurate tree-height information (Gatziolis and Andersen, 2008) and a higher percentage of ground returns. Scan angle is important for forestry applications, because a higher scan angle increases the distance a pulse must travel through the canopy before reaching the ground surface. This can reduce the number of ground returns and the accuracy of elevation and height measurements. A

scan angle of $\leq 13^\circ$ increases the probability that the lidar pulse will penetrate heavy forest cover and adequately sample the forest structure. Keep in mind, however, a narrower scan angle increases the number of flight lines required and in turn increases cost (Andersen et al, 2006). Sidelap refers to how much overlap exists between scanning swaths. Fifty percent sidelap provides 100% total overlap, so each area is being scanned twice. Ensuring 100% sidelap in conjunction with opposing flight lines is crucial for forestry acquisitions to eliminate data occlusions (data shadows) from vegetated areas.

One final consideration is that 3DEP acquisitions are *often* flown during “leaf-off” conditions because the main focus is on efficiently acquiring topographic (e.g., bare earth) products. Therefore, if you are partnering with 3DEP for an acquisition, you may consider negotiating for “leaf-on” conditions during the acquisition if obtaining forest structure is imperative to your project. If leaf-off data is your only option you will still be able to obtain canopy height information, but canopy cover and density values will be negatively skewed in deciduous canopies. All the considerations mentioned above are outlined in more detail in Section 5 of the Appendix (pg. 13-14).

Information for Vendor

The first step in working with a vendor is communicating what they need to know in order to fulfill your data requirements. In addition to typical specifications for the lidar acquisition, it is important to clearly communicate items that should be included in the contract and with the delivery in order to acquaint the vendor with project-specific requirements. Such items include:

- The location of the acquisition area, including a narrative, maps, and shapefile(s)
- Potential problems the vendor needs to be aware of, such as flight-restricted areas and ground access
- The lidar survey specifications (Section 5 of the [Appendix](#))
 - Data-acquisition parameters
 - Accuracy specifications
 - Completeness and consistency of the data set
 - Spatial reference framework (datum, projections, units, etc.)
 - Deliverables
 - Formats and data organization (consistent file names, accessible file formats)
- Time frame for data acquisition and delivery
- Contact information for communication between vendor, client and local points of contact
- Insurance/liability clauses
- Contract nullification conditions
- Data ownership

For a more complete look at what to include in a contract, an example Statement of Work for an actual lidar acquisition is included in the [Appendix](#).

Lidar Derived Products

Airborne lidar surveys generate data-rich point clouds made up of millions/billions of points that represent the world in a collection of x, y and z coordinates. To extract useful geospatial information from the point cloud, filtering and classification algorithms are used to generate additional geospatial products, or “lidar derived products,” from the raw point clouds. The lidar derived products provide 3-D information (typically in raster format) across large landscapes to land managers that were not available prior to the collection and manipulation of the point cloud. Below we have categorized lidar derived products into three categories based on which data source it was derived from and who would typically derive it. These categories are designed to assist potential users in understanding how products are generated and what level of effort is typically involved to create them, they include: 1. Point cloud derived products (vendor created), 2. Raster derived products (client created) and 3. Point cloud derived products (client created).

1. *Point Cloud Derived Products (vendor created):*

Typical acquisitions (as specified by the Statement of work, see [Appendix](#)) include a few of the most commonly used lidar products to be derived and delivered by the vendor in addition to the raw point cloud. The products typically delivered by the vendor are ready to be used as is in a GIS and do not require point cloud processing.

- **Bare earth surface model:** a high resolution (1 meter) Digital Elevation Model (DEM) that provides improved topographic information and 3-D viewing of the landscape. It is generated by filtering the raw point cloud to identify “ground returns” and then creating a bare earth surface from the filtered points. Note: It is highly recommended that you pay the lidar vendor to generate this product; in most cases it is a cost savings.
- **Highest hit (first return) surface model:** derived by creating a surface from the first return of each pulse. It is essentially a 3-D model of all objects on the surface of the earth such as trees, buildings, and infrastructure superimposed on the topography. It contains elevation values above sea level rather than “height” above ground. The highest hit surface provides a realistic 3-D model of the complete environment.
- **Intensity image:** derived from the amount of infrared energy reflected back to the sensor in each lidar return. This information can be turned into an intensity image, which is a high-resolution image (typically 1 meter) with values corresponding to a normalized infrared reflection (similar to an orthophoto) and is typically used for qualitative analysis and reference imagery.

2. *Raster Derived Products (client created):*

The following layers can be derived from the vendor delivered raster products using basic GIS analysis and do not require further point cloud processing.



- **Canopy height model:** derived by subtracting the bare earth surface model from the highest hit surface model. This results in canopy and tree height above the ground in forested areas along with the height of other objects in non-forested areas (bridges, powerlines, buildings etc.).
- **Hillshade model (bare earth, canopy height and highest hit):** a black and white rendering that highlights elevation/height changes in the landscape. The surface is illuminated by a hypothetical light source, making elevation/height changes easier to visualize.

3. Point Cloud Derived Products (client created):

To further exploit the lidar data, there are a number of forest composition metrics – referred to as “first order lidar metrics” – that can be derived from the raw point cloud to explain the canopy structure in terms of height, cover and density statistics (McCallum et al., 2014; Mitchell et al., 2015). A complete list of canopy structure metrics that can be generated from the point cloud are described in the FUSION software manual (http://forsys.sefs.uw.edu/fusion/FUSION_manual.pdf). In addition, RSAC has compiled “First Order Lidar Metrics: A Supporting Document for Lidar Deliverables” (http://www.fs.fed.us/eng/rsac/lidar_training/pdf/LidarMetricsDescriptionOfDeliverables_Generic_12_15_14.pdf) to aid USFS staff in confidently characterizing forest canopy structure.

- **Height metrics:** A number of statistics are produced that describe the canopy height at a specified scale (grid cell size). These metrics include basic distribution statistics such as the mean, mode, variance and maximum height values among many others.
- **Cover metrics:** This group of statistics includes different measurements of canopy cover and canopy density. Canopy cover is calculated by taking a ratio of first returns above a height threshold divided by the total number of first returns. This is comparable to photo interpreted estimates of canopy cover but more consistent across large landscapes. Canopy density is calculated by taking the ratio of all returns above a height threshold divided by the total number of all returns.

Summary

The lidar acquisition specifications needed to characterize the forest structure are provided in this document, therefore it is up to the user to work with partners to create a Statement of Work that captures the necessary specifications. 3DEP provides an ever increasing opportunity to collaborate on lidar acquisitions and share costs, but you must be aware of the four QL’s and understand that not all of the levels will meet forestry application needs. For further information or lidar acquisition consultation, please contact your Regional Remote Sensing Coordinator or the Geospatial Technology and Applications Center, and they will assist you in taking full advantage of the lidar resources available to you.



References

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Appendix – Statement of Work

[Note: Replace green text with project-specific information]

Solicitation _____

Lidar Acquisition

Four Forests Restoration Initiative (4FRI) 2nd EIS Phase 2

Apache-Sitgreaves National Forests

USDA Forest Service Southwestern Regional Office

Albuquerque, NM

1) STATEMENT OF WORK

The purpose of this task is to:

- a. Acquire lidar data for the Phase 2 of the 2nd EIS area for the Four Forests Restoration Initiative (4FRI) on the Apache-Sitgreaves National Forests located in Arizona.
- b. Process and deliver the lidar data to the Southwestern Regional Office Remote Sensing Unit (Contact information below.)

The contractor shall provide all equipment, labor, and materials necessary to map forest structure within the ponderosa pine, mixed-conifer, and pinyon-juniper forest types using Light Detection and Ranging (lidar) technology. The project area covers Phase 2 of the 2nd EIS area of the 4FRI project as well as additional acreage of FS lands extending to the forest boundary on the Sitgreaves National Forest in Arizona. The data will be used primarily to identify areas for implementation of forest restoration treatments designed to restore resiliency and sustainability to frequent-fire forest types.

The vast majority of the technical specifications for this document were borrowed from the Specifications outlined by the Oregon Lidar Consortium in their Lidar specifications document. The Data Quality Assurance procedures were developed by the Remote Sensing Applications Center.

2) TECHNICAL SPECIFICATIONS

4FRI 2nd EIS Phase 2 acquisition specs

1. Acquisition Area:



The acquisition area contains approximately approx. 1,062,225 contiguous acres of the Apache-Sitgreaves National Forests in Arizona (see Figure 1 and attached shapefile *4FRI_ph2_bnd*). Of this, approx. 785,300 acres are within the 4 FRI project boundary and another 259,500 acres are additional pinyon-juniper areas that extend to the forest boundaries. The rest of the acreage is due to the 100 meter buffer applied to the project boundaries.



Figure 1. Overview of project area with acquisition area shown in red

2. Purpose of the study:

The data products will be used primarily to identify areas for implementation of forest restoration treatments designed to restore resiliency and sustainability to frequent-fire forest types.

3. Potential acquisition problems:

- Limited time of year suitable to acquire leaf-on data (acquisition window May 21 – September 30.)
- The ground should be generally clear of snow with the exception of a few remaining snow banks
 - Snow season: December to April
- The area of interest has an elevation range of 6000 ft. to 11000 ft.
- Acquisition should be conducted when no smoke from wildfires or prescribed burns is visible over acquisition area
- Monsoon season (July thru mid-September) typically has cloud buildup over higher elevations by 11am
- The area of interest corresponds to the Phase 2 of the 2nd EIS area on the 4FRI project plus some additional pinyon-juniper areas on the Apache-Sitgreaves National Forests
 - The red AOI (1,062,225 acres) contains the Phase 2 area and the pinyon-juniper areas with a 100 meter buffer

4. Air space restrictions:

The Contractor shall coordinate with the Federal Aviation Administration for air space restrictions.

5. Data acquisition & Completeness:

The table below outlines the desired acquisition parameters. The data will be routinely evaluated for completeness (as defined in Data Quality and assessed in the Data Quality Assurance section).



Data acquisition	Survey Design	Minimum requirements ¹
Wavelength	900-1600 nm discrete return	
Returns per pulse	4 or more	
On-ground laser beam diameter	Approx. 25 cm, Use Narrow divergence setting – if instrument allows for it	Between 10 cm and 100 cm
Scan angle	± 13 degrees	≤ ± 20 degrees
Aircraft altitude	For vendor to determine	
Aircraft speed	For vendor to determine	
Ground swath width	For vendor to determine	
Swath overlap	50% sidelap (100% overlap)	<p>Between 30% and 50% sidelap</p> <p>100% double coverage at planned aircraft height above the ground.</p> <p>No voids between swaths.</p> <p>No voids because of cloud cover or instrument failure</p> <p><20% no overlap area per project.</p> <p>No arbitrary 1km x 1km square with >50% no-overlap area.</p>
Aggregate pulse density	8 pulses/m ²	<p>Barring non-reflective areas (e.g. open water):</p> <ul style="list-style-type: none"> • Minimum of 8 pulses/m² for ≥85% of the project area • no 100m x 100m area with <50% design pulse density (4 pulses/m²) • in areas of large terrain relief, more closely spaced flight lines may be necessary to meet minimum point density and double coverage
Intensity Normalization	Normalize for automatic gain	Document steps used to process intensity values, including any taken to improve consistency of intensity values across the study area.
Flight line direction	Opposing	



GPS base line length	≤50 km	
GPS PDOP	<p>≤3.0, ≥6 satellites in view of both a stationary reference receiver and the roving receiver</p> <p>Made with dual freq. L1-L2 receivers with carrier-phase correction</p>	
Survey conditions		Leaf-on and no significant snow

1. Local relief, turbulence, inability to maintain an exact flying height, and aircraft and instrument availability routinely lead to departures from the survey design. *Minimum requirements* listed here are the minimum acceptable under this contract.

6. Survey execution:

Contractors must fully describe all steps taken to calibrate the aircraft’s onboard inertial measurement unit (IMU) and sensor offsets/settings. Surveys should be conducted in leaf-on conditions with no significant snow cover and should be conducted between May 21 and September 30. Any snow covered areas will have unreliable bare earth surfaces and hence unreliable vegetation canopy metrics.

7. GPS Procedures:

Contractors must fully describe GPS procedures (including GPS instrument specifications) used to establish the following:

1. The spatial reference (coordinate) framework and vertical datum that will be used for the purposes of lidar data collection and survey reduction; and,
2. The collection and processing of ground control points (GCP’s) for the purposes of undertaking lidar QA/QC by the applicant.

All GPS measurements shall be made with dual frequency L1-L2 receivers with carrier-phase correction. All GPS measurements shall be made during periods with PDOP less than or equal to 3.0 and with at least 6 satellites in common view of both a stationary reference receiver and the roving receiver.

Stationary reference receivers shall be located at existing National Geodetic Survey (NGS) marks or at new marks. In the case of an existing mark, its location shall be verified by processing one GPS session of at least two hours duration and comparing the computed position with the position published by NGS. Each new mark shall be located by tying to one or more NGS Continuously Operating Reference Stations (CORS) by static GPS methods. If the distance to the nearest CORS is less than 80 km, use at least 2 independent GPS sessions, each at least 2

hours long. If the distance to the nearest CORS is greater than 80 km, use at least 2 sessions each at least 4 hours long.

At least two GPS reference receivers shall be in operation during all lidar missions, sampling positions at greater than or equal to 1 Hz. The roving GPS receiver in the aircraft shall sample positions at greater than or equal to 2.0 Hz. Differential GPS baseline lengths shall be no longer than 30 km.

Ground control points (GCPs), used for both survey calibration and assessment of absolute vertical accuracy, shall be established using GPS and (or) other techniques that are expected to result in accuracies of 1.5 cm (RMSE) or better. Strongly clustered GCPs are useful, perhaps even desirable, for calibration. Vertical accuracy shall be assessed by calculating and averaging the distances between a subset of at least 30 GCPs that are not clustered and a surface interpolated from lidar last returns. At least 20% of flight line swaths should contain points in this subset and the maximum distance between these GCPs should be no less than one-half the maximum distance across the survey area.

The Report of Survey shall document the identity, published position, and measured position of all existing NGS marks used for reference stations. The locations of new marks shall be described, along with their measured positions, photos of the new marks and the identity and published positions of CORS to which their locations were tied. The Report of Survey shall describe the technique(s) used to establish GCPs and document the positions and residuals of all GCPs used to evaluate survey accuracy.

3) PROJECT DELIVERABLES

1. Spatial Reference Framework:

Vertical datum	NAVD 88, Geoid 12A
Horizontal datum	NAD83
Projection	UTM zone 12
Units	meters

Data shall be delivered in tiles that are rectangular in geographic coordinates, corresponding to standard USGS 7.5-minute quadrangles and divisions thereof, and are named according to the scheme (note that letters used in filenames shall always be in lower-case):



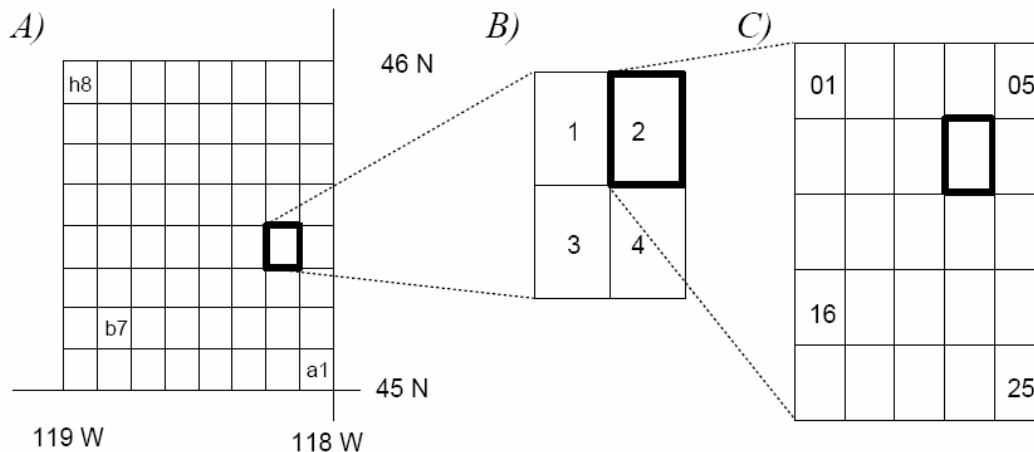
AAOOORCQ (quarter-quadrangle, 3.75 minute by 3.75 minute region)

AAOOORCQNN (1/100th quadrangle, 0.75 minute by 0.75 minute region)

where AA is the integer north latitude of the SE corner of the 8 by 8 region that contains the quadrangle, OOO is the integer west longitude of the SE corner of the 8 by 8 region, R is the row, labeled from **a** to **h**, south to north, and C is the column, labeled from **1** to **8**, east to west. That is, in diagram A below of the 8 by 8 region with a southeast corner at 45N, longitude 118W, the highlighted quadrangle is 45118d2.

Q is the quadrangle quadrant, which shall be numbered west-to-east, north-to-south, as is shown in diagram B below. That is, the highlighted quarter-quadrangle tile in diagram B is 45118d22.

QNN identifies the 1/100th quadrangle, which shall be labeled by numbering the 25 divisions of each quarter-quadrangle west-to-east, north-to-south, as shown in diagram C below. That is, the highlighted tile in diagram C is 45118d2209.



Report: Deliverables the Contractor shall provide to the Authorized Purchaser include a Report of Survey, Aircraft trajectories, .las format all-return point files, Ground (Bare-earth) DEM, Full-feature (highest-hit) DEM, ground point list, intensity image, and formal metadata . The **Report of Survey** shall be a digital text report that describes survey methods; results; Contractor’s accuracy assessments, including internal reproducibility and absolute accuracy; file formats; file naming schemes; tiling schemes.

Aircraft trajectories: (SBET files) shall be ASCII point files or ESRI shape files, with aircraft position (easting, northing, elevation) and attitude (heading, pitch, roll) and GPS time recorded at



regular intervals of 1 second or less. May include additional attributes, such as temperature and humidity or other relative information the contractor deems appropriate.

All-return point cloud: shall be .las v1.4 format files listing all valid returns; all fields populated. For each return: GPS week and GPS second OR Posix time, easting, northing, elevation, intensity, return #, return classification. May include additional attributes. No duplicate entries. Time shall be reported to the nearest microsecond or better. Easting, northing, and elevation shall be reported to nearest 0.01 meter (nearest 0.01 feet). Classification of returns shall be as complete as is feasible and without avoidable return misclassification. 1/100th USGS 7.5-minute quadrangle (0.75 minute by 0.75 minute) tiles.

Bare-earth filtered point cloud: Shall be .las v1.4 file containing only returns identified as ground returns.

Bare-earth surface model (DEM): Raster of ground surface, interpolated via triangulated irregular network from identified ground points. Grids shall conform to the following specifications: ESRI floating point grid, 1 m cell size, snapped to (0, 0), 1/4th USGS 7.5-minute quadrangle (3.75 minute by 3.75 minute) tiles. The triangulated irregular networks from which ground surface raster models are interpolated should not include break lines derived from other data sources. Surface models shall have no tiling artifacts and no gaps at tile boundaries. Areas outside survey boundary shall be coded as NoData.

First-return (highest-hit) surface model (DSM): Raster of first-return surface, cell heights are highest first return within that cell, cells without first returns shall be coded as NoData. Shall conform to the same file and grid formats as Bare-earth surface model (DEM). 1/4th USGS 7.5-minute quadrangle (3.75 minute by 3.75 minute) tiles. Surface models shall have no tiling artifacts and no gaps at tile boundaries. Areas outside survey boundary shall be coded as NoData.

Intensity image: Raster of 1st-return intensity. Vegetation analysis using the intensity image requires that values be consistent. The Contractor must document how the intensity image is calibrated or normalized to reduce inconsistencies that limit its utility for analysis. TIFF, 1 m pixel size, 1/4th USGS 7.5-minute quadrangle (3.75 minute by 3.75 minute) tiles.

Surface models shall have no tiling artifacts and no gaps at tile boundaries. Areas outside survey boundary shall be coded as NoData.

Supporting shapefiles:

- 1) A shapefile of all ground survey monument points established by the vendor for the project.
- 2) Shapefiles of the tiling tessellation (polygon feature) for the bare earth models and the lidar tiles.

- The attribute name for each tile in the index shapefiles must match exactly the name of its corresponding *.las or ArcGRID file. Letters used in names shall be lower-case.
- 3) Shapefiles with the tracking of the individual flight lines and flight line swaths (line and polygon features, respectively).

Formal metadata: GIS-compatible data and files shall be explained with XML format metadata that follows the Federal Geographic Data Committee's (FGDC) Content Standard for Digital Geospatial Data. Metadata may be a single file that describes an entire survey or multiple files each of which describes a constituent part (e.g., area A, area B, area C) of the survey. Metadata should be completed for all deliverables, including point clouds, DEM, DSM and Intensity images as well as shapefiles. Metadata shall include, but is not limited to, the following:

Under Identification Information

Description, Abstract

An abstract summarizing the datasets delivered. Include project area.

Include general tiling scheme (e.g., USGS 7.5 quarter quad). For each data layer, describe

Data structure and attributes, including resolution and precision

Total number of files

Time Period

Date(s) of data capture (range of dates)

For these dates, use the Current Reference: ground condition.

Status

Statement regarding completeness status.

Spatial Domain, Bounding Coordinates and G-Polygon

Project survey area bounding coordinates in decimal degrees

Data Set Credit

Name and address of the Contractor.

Names of the agencies that contributed funds and participated in the acquisition of the data. Other citation details for explanation of the data acquisition project. The

names of these agencies will be provided to the Contractor by the Authorized Purchaser.

Under *Data Quality*

Process Step

Process Description for manufacturer, model, and serial number of lidar instrument(s). May include separate specifications for scanning laser rangefinder, inertial navigation system, and GPS unit Value(s) of instrument parameters during survey, including

Nominal on-ground beam diameter pulse rate

Maximum number of returns recorded

Minimum separation between detected returns from a single

Pulse, expressed as a distance

Laser output power

Minimum return power required to produce a return

Beam wavelength

Frequency of GPS sampling

Frequency of IMU sampling

Nominal swath width

Nominal single-swath pulse density

Nominal aggregate pulse density

Identity and assumed coordinates of reference survey monument(s)

Nature of vertical control (e.g., RTK GPS or water surface + tidal

Observations)

Calibration procedures

Return classification procedures

Positional Accuracy



Vertical Accuracy Report. Accuracy may be specified as RMSE or 95% confidence (indicate which). Vertical accuracy shall be reported for lidar measurements and, optionally, for the derived ground (bare earth) surface model. XY accuracy of lidar measurements may also be reported. Shall include one or more of the following sections:

Accuracy as predicted by creator of survey

Accuracy as measured by creator of survey

Accuracy as verified by contracting agency or independent

3rd party.

The accuracy as verified by the contracting agency or independent 3rd party will be provided to the Contractor by the Authorized Purchaser.

Under Spatial Data Organization Information

Indirect Spatial Reference

Tiling scheme (if any). (e.g. .las data is divided into 1/100th USGS 7.5” quad)

Under Spatial Reference Information

Horizontal Coordinate System Definition:

Geographic Coordinate System for the captured data

Projected Coordinate System for the delivered data

Horizontal Datum for the delivered data

Ellipsoid Name (identify both the ellipsoid and the geoid model used to translate from ellipsoid to orthometric heights)

Vertical Coordinate System Definition

Datum Name

Vertical units

Under *Entity and Attribute Information*

Overview Description, Entity and Attribute Overview

Attribute descriptions if applicable (e.g. user bit field in .las format).

For all-return data, definition of return classification codes. Any other relevant attribute information.

Under *Distribution Information*

Distributor

Distribution point of contact

The distribution point of contact will be provided to the Contractor by the Authorized Purchaser.

Standard Order Process

Ordering Instructions - web location, if applicable

The ordering instructions will be provided to the Contractor by the Authorized Purchaser.

Distribution Liability

Absence of intellectual property restrictions

The absence of intellectual property restrictions will be provided to the Contractor by the Authorized Purchaser.

Under *Metadata Reference Information*

Metadata Contact

Details for author(s) of metadata. The details shall include the name of the Contractor's personnel, telephone number and email address.

Metadata Standard Name

“FGDC Content Standards for Digital Geospatial Metadata”

Metadata Standard Version

“FGDC-STD-001-1998” unless updated or otherwise substituted

Usability: Names of data files shall be composed of the tile name followed, in some cases, by a suffix that denotes the data layer and (or) the file format. In some cases this name shall have additional suffixes that denote an export file and (or) file compression.

For the quarter-quadrangle 45123a3 and constituent 1/100th-quadrangle tile

45123a301, these are the names of data files:

All-return point cloud

45123a301.las (.las file)

Ground (bare-earth) surface model

45123a3be (ESRI grid name)

45123a3be.e00 (ESRI export file)

First-return (highest-hit) surface model

45123a3hh (ESRI grid name)

45123a3hh.e00 (ESRI export file)

Ground point list

45123a3 (ESRI shapefile)

First-return (highest-hit) intensity image

45123a3hh.tif (TIFF image; with accompanying .tfw file)

Files shall have consistent formats.

Some of the QAQC processes are case-sensitive. So, for the processes to run properly, the file name for each 1/100th quadrangle tile in the index shapefile must match exactly the name for its corresponding *.las file. For the sake of consistency, all filenames should contain only lower-case letters.

Contractor shall propose all details of file names and file formats that are not specified here. Contractors proposed names and formats must be approved by Authorized Purchaser. GIS (ESRI grids, shapefiles) shall have complete and correct associated projection files.

All files must be readable.

Failure of data to meet format specifications, files that have inconsistent internal formats or are not readable, GIS data that have incomplete or incorrect associated projection files shall result in reformatting and re-delivery.

Descriptive file list documenting all of the delivered files.

Deliverable media: USB 3.0 external hard drive

2. Delivery Schedule:

Contractor shall provide digital data to Authorized Purchaser on new portable hard drives at Contractor’s expense. The final delivery shall be made no later than 60 Business Days from end of data acquisition. The data acquisition timeline shall be mutually agreed upon by the Authorized Purchaser and the Contractor. Authorized Purchaser will review and accept or reject products within 30 Business Days of delivery. Following a thorough Quality Assurance (as outlined in #4 Data Quality Assurance) review by Authorized Purchaser staff, data will be accepted or rejected based on the data products meeting the Technical Specifications.

3. Data Quality:

Survey data shall meet or exceed requirements, described below, for within-swath reproducibility, first-return swath-to-swath reproducibility, absolute accuracy, completeness, and surface quality. Authorized Purchaser may reject data if it can demonstrate, to the satisfaction of the Contractor or a qualified independent observer, that data do not meet Technical Specifications. Rejection of data shall result in, at the discretion of Authorized Purchaser, rework (including reacquisition if necessary), non-payment or re-negotiation of payment. At Authorized Purchaser’s discretion, Authorized Purchaser and Contractor may negotiate partial non-payment for partially unsatisfactory data (see Data Quality Assurance section). There shall be no charge and no additional mobilization fee for any necessary re-acquisition.

Within-swath reproducibility—Single-swath data from planar surfaces shall show no departures from planarity greater than 10 cm for project as a whole, and the average (RMSE) departure from planarity within any 10m x 10m area shall be no greater than 5 cm.

First-return swath-to-swath reproducibility—Absent real changes in surface elevation between successive measurements, the root mean square vertical error as estimated by the internal reproducibility of a survey shall not exceed 15 cm. This value shall be established by averaging of reproducibility determined from suitable near-planar areas across an entire survey (50 mi² minimum) area. Vertical errors may be greater on sloping surfaces; error will be normalized by the following rule:

$$\text{Normalized error} = \text{observed error} / (1 + \text{slope}\% / 29.7 + \text{slope}\%^2 / 8500)$$

This rule is equivalent to the following permissible errors (with errors on intermediate slopes obtained by interpolation):

Slope	Elevation reproducibility (RMSE)
0 degrees	15 cm
20 degrees	35 cm
50 degrees	100 cm

In addition, no arbitrary 1 km by 1 km area shall have estimated slope-normalized vertical RMSE \geq 20 cm.

Absolute vertical accuracy— Bare-earth DEMs, as tested by Contractor against independent GCPs, on flat surfaces, in areas where ground control resolution is both high and likely to truly characterize the ground surface, must have a vertical RMSE no greater than 10.0 cm. If the absolute accuracy fails to meet the specification, Contractor and customer will investigate all statistics and distribution of ground control points to assess the nature and causes of outliers influencing the overall accuracy of the data.

Completeness— Minimum acceptable swath overlap and aggregate 1st-return density are:

1. Coverage: No voids between swaths
2. Coverage: No voids because of cloud cover or instrument failure
3. Swath Overlap: Less than or equal to 20% no-overlap area per project area.
4. Swath Overlap: No arbitrary 1 km by 1 km area with less than 50% double coverage
5. Aggregate 1st return density: Barring non-scattering areas (e.g.: open water, wet asphalt)
 - a. Greater than or equal to the design pulse density (8/m²) for \geq 85% of the project area.
 - b. Within any 100m x 100m area within swath overlap, greater than or equal to 50% design pulse density

Surface quality—there shall be no tile-boundary artifacts, no voids between DEM tiles, and no avoidable misclassification of returns.

4. Data Quality Assurance

A thorough quality assurance assessment will be conducted by the Authorized Purchaser to determine if the lidar data deliverables meet the specified Technical Specifications. The procedure for assessing the quality of the data is outlined below.

1. Using FUSION software –

- a. Use the catalog DOS command to assess pulses per sq. meter to determine if the dataset meets the Technical Specifications, averaged over a 100m by 100m area.*
- b. Use the catalog DOS command to flag tiles with potential elevation outliers.
- c. Visual inspection – inspect 3D point cloud for all tiles for outliers, holes, gaps, etc.
- d. Use catalog DOS command graphical output to visually inspect flight line overlap (50% sidelap, 100% overlap) based on pulse density.

*1. Cells intersecting with the project area perimeter will not be assessed
 2. As defined by NHD, cells containing polygon water features (e.g. StreamRiver and LakePond) will not be assessed, however, cells containing line water features *will* be assessed in the Quality Assurance assessment.

2. Using ArcGIS software –

- a. Visual inspection of Bare-earth surface model (DEM) – looking for tile boundary artifacts, gaps and holes.
- b. Visual inspection of First-return (highest-hit) surface model (DSM) - looking for tile boundary artifacts, gaps and holes
- c. Visual inspection of flight line shapefile for opposing flight line pattern.
- d. Review shapefiles for coverage and completeness and ensure they include correct naming convention, metadata, and attributes.

If it is determined that the acquired lidar data is insufficient based on the Quality Assurance assessment, the Contractor may be required to reprocess and/or re-fly problem areas to receive full-payment or may be asked to re-negotiate a reduced price of the lidar deliverables. Each Quality Assessment cell (100m by 100m) that does not meet the minimum Technical Specifications of 4 pulses/square meter may cause a reduction in payment to the Contractor equivalent to the cells percentage of the total area surveyed. If 3 percent or more of the Quality

Assessment cells do not meet the minimum Technical Specifications, then the Authorized Purchaser has the right to re-negotiate a reduced price of the lidar deliverables.

SPECIAL PROVISIONS

3.1 Inspection: Contractor’s facilities and equipment shall be subject to inspection at any time by a representative of the Authorized Purchaser.

3.2 Ownership of Data: All products, data, information, findings and documents prepared or obtained under the terms of this Price Agreement shall become the exclusive property of the Authorized Purchaser.

3.3 Access Agreements: The Contractor shall provide written notification to the Authorized Purchaser on the number and locations of ground control points used in this Price Agreement. The Contractor shall determine land ownership encompassing those locations and as required, obtain site access permission. The Contractor shall notify landowners and coordinate with the appropriate personnel prior to on-site or over-site activities. The Contractor shall be solely responsible for the requisite filing of flight plans and obtaining appropriate permissions from the FAA and other agencies as necessary.

3.4 Key Personnel: Contractor and the Government agree that each individual specified below is an individual whose special qualifications and involvement in Contractor’s performance of Services form part of the basis of agreement between the parties for this Contract and is an individual through whom Contractor shall provide to Authorized Purchaser the expertise, experience, judgment, and personal attention required to perform Services (“Key Person”). Each of the following is a Key Person under this Price Agreement:

[List name, title, identify the specific services each Key Person is required to perform under this Price Agreement.]

Neither Contractor nor any Key Person of Contractor shall delegate performance of Services any Key Person is required to perform under this Price Agreement to others without first obtaining Authorized Purchaser’s written consent. Further, Contractor shall not, without first obtaining Authorized Purchaser's prior written consent, reassign or transfer any Key Person to other duties or positions so that the Key Person is no longer available to provide Authorized Purchaser with that Key Person’s expertise, experience, judgment, and personal attention. If Contractor requests Authorized Purchaser to approve a re-assignment or transfer of a Key Person, Authorized Purchaser shall have the right to interview, review the qualifications of, and approve or disapprove the proposed replacement(s) for the Key Person. Any individual Authorized



Purchaser approves as a replacement for a Key Person is deemed a Key Person under this Price Agreement.

PAYMENT

The contractor will submit all invoices using the IPP, Invoicing Processing Platform (<https://www.ipp.gov>). The contractor will submit an invoice for 50% of the total fee after the data acquisition is complete, and an invoice for the balance after deliverables are provided. The invoice for the first 50% of the total fee shall be deemed valid and accepted unless the contractor is notified within 14 calendar days after the receipt of invoice that the claim is rejected. The invoice for the balance of the total fee shall be deemed valid and accepted unless the contractor is notified within 30 business days after the receipt of invoice that the claim is rejected. In that event, reasons for such rejection shall be stated in a Notice of Rejection of Claim, which is sent using an expedient service with confirmation of delivery.

EVALUATION FACTORS FOR AWARD

Award Determination

Award will be made to the offer whose proposal is considered to be the best value to the Government, price and other factors considered. The Government intends to award this contract without discussions.

The factors listed below under Price Proposal will account for 40% of the evaluation and the factors listed under Technical Proposal will account for 60% of the evaluation.

Evaluation Factors

A. Price Proposal

Furnish price for all services and materials to complete the work described herein, including appropriate taxes. No additional information will be necessary to determine the reasonableness of price.

B. Technical Proposal

Past Performance – Including: timeliness of performance; quality of service, and business relations. Provide examples of previous (within the past three years) large-area projects where LiDAR data were acquired for forest structure applications.

Technical Approach, Current Project - Provide a description of the technical approach to be implemented on this project.





Include contract information for previous purchasers to include: Name of Project, Location of Project, Date of Project, Dollar Amount of Project, Project Manager Name and Contact Information (email, phone number).

Points of Contact:

Four Forest Restoration Initiative

- Dick Fleishman, Acting 4FRI Team Leader, dfleishman@fs.fed.us, 928-226-4687 (office)
- 4FRI Silviculturist, [TBD]
- Mark Nigrelli, GIS Specialist mnigrelli02@fs.fed.us, 928-226-4688 (office)

Forest Service Southwestern Regional Office:

- Tom Mellin, Remote Sensing Unit Leader and Project Lead, tmellin@fs.fed.us, 505-842-3845 (office), 505-301-8167 (cell)
- Pete Joria, Remote Sensing Analyst, pjoria@fs.fed.us, 505-842-3821 (office)
- Carol Boyd, Deputy Director Forest Management, cboyd@fs.fed.us, 505-842-3240 (office)

Apache-Sitgreaves National Forest

- Mark Empey, Aviation Officer, mempey@fs.fed.us, 928-333-6315 (office), 928-240-0978 (cell)

Contracting Officer

- Rufus Cole, Contracting Officer, rcole01@fs.fed.us, 505-842-3342 (office)

