Statement of Work
For the Acquisition and Production of High Resolution Elevation Data for Portions of Blanco, Burnet, Comal, Guadalupe, Kendall, and Kerr Counties

1. Introduction

This Statement of Work is issued to acquire high resolution elevation data and associated products from airborne LiDAR systems. This document contains specifications, and identifies a specific area of interest (AOI). The AOI is directly affected by funding availability and interested parties and is subject to change.

The data acquired will become part of an ongoing data collection by the State of Texas to support mapping and modeling of flood plains, hydrography, and terrain.

The data are intended to exceed requirements for Federal Emergency Management Agency (FEMA) specifications for Flood Plain Mapping as well as serve as an input to the U.S. Geological Survey refinements to the National Elevation Dataset. The products acquired by this contract will be made available in the public domain through the Texas Natural Resources Information System (TNRIS) for use by government, and the public.

1.1 High Resolution Elevation Data Program Goals

It is the intent of the High Priority Imagery and Datasets Program to purchase products that will provide direct savings, efficiencies, cost and duplication avoidance through inter-governmental collaboration and partnerships.

1.2 Accuracy and Quality of Products

This program uses commercial data providers to collect and process data and separately selects third party quality assurance consultants to review products and processes. Each participant in the program is expected to maintain internal quality controls and assurances for minimizing errors and to document the procedures for ensuring data will meet or exceed requirements.

All surveying activities are expected to verify geodetic and control parameters with the Texas Spatial Reference Center and TNRIS prior to performing work.

1.3 Boundary Matching

This project borders areas where LiDAR data have been previously acquired. Respondents are encouraged to provide details describing solutions that will ensure data continuity across existing and newly acquired data.

2. Project Phases

Each phase of this project requires attention to quality assurance processes to guide the planning and production tasks. The following tables represent key elements of the project that affect the quality and accuracy of the final products.

Table of Primary Project Tasks	
Phases of Work	**LiDAR Provider**
Phase I **Pre-Flight Planning**	1. Confirm specifications with state 2. Develop Flight Operations Plan 3. System calibration and geodetic control validation
Deliverables	1. Project Plan including projected milestones 2. Flight Plans for assigned Area(s) of Interest (AOI) 3. Calibration report 4. Monthly compliance report
Phase II **Data Acquisition**	1. Perform flight setup and geodetic control process 2. Fly project area and collect data 3. Verify data after each flight and mission
Deliverables	1. Flight trajectories and GPS Report 2. Report data acquisition completion to QA Vendor and TWDB 3. Monthly compliance report
Phase III **Data Processing**	1. Classify point data 2. Produce intensity images 3. Create hydro-flattening breaklines
Deliverables	1. Classification accuracy report 2. Intensity image, point cloud and breaklines in digital format 3. Breakline data files approved by third party QA/QC 4. Monthly compliance report
Phase IV **Product Development**	1. Create Digital Elevation Models 2. Generate tile and project level metadata
Deliverables	1. Digital Elevation Models on portable external drives 2. Tile and project level metadata per product 3. Monthly compliance report

* Project schedule to be determined at project kick-off.
**All products to be delivered to TWDB unless otherwise specified.
***Invoice for each phase not to exceed 25% of total negotiated amount unless approved by State Contract Manager.

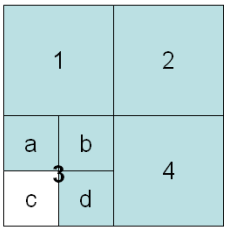
2.1 Standard Specifications for LiDAR Providers

The following table outlines the specifications for data acquisition, accuracy, spatial reference framework and deliverables.

Data Acquisition					
Requirement	Description	Urban	Forest	Coastal	Flood/Soils
Returns per pulse	LiDAR sensor shall be capable of recording up to 3 (or more) returns per pulse, including 1st and last returns	*	*	*	*
Scan angle	From center scan angle ≤ ±20 degrees. Full scan angle ≤ 40°.	≤ ±20°	≤ ±20°	≤ ±20°	≤ ±20°
Swath overlap	Nominal 50% side lap on adjoining swaths, i.e., survey shall be designed for 100% double coverage at planned aircraft height above ground	50%	40%	30%	30%
Design pulse density	Pulses/m2 (includes swath overlap; e.g., with 50% side lap, ≥ 2 pulse/m2 in each swath)	≥4	≥4	≥4	≥4
GPS procedures	At least 2 GPS reference stations in operation during all missions, sampling positions at 1 Hz or higher frequently. CORS stations will be selected in consultation with the Texas Spatial Reference Center. Differential GPS baseline lengths shall not exceed 30 km. Differential GPS unit in aircraft shall sample position at 2 Hz or more frequently. LiDAR data shall only be acquired when GPS PDOP is ≤ 3.5 and at least 6 satellites are in view.	*	*	*	*
Survey conditions	Leaf-off and no significant snow cover or flood conditions, as observed by state contract representatives. Cloud and fog-free between the aircraft and ground.	*	*	*	*
Accuracy					
		Urban	Forest	Coastal	Flood/Soils
Horizontal Accuracy	RMSEr	< 50 cm	< 75 cm	< 50 cm	< 75cm
Vertical Accuracy	RMSEz	< 10 cm	< 25 cm	< 12 cm	< 15 cm

Geographic Coverage and Continuity	
Coverage	No voids between swaths No voids because of cloud cover or instrument failure
Swath overlap	≤ 40% no-overlap area per project
Aggregate 1st return density	Barring non-scattering areas (e.g., open water, wet asphalt): For entire project area, ≥ 85% design pulse density Within any 30m x 30m area within areas of swath overlap, ≥ 50% design pulse density
Spatial Reference Framework	
Vertical Datum	NAVD88, Geoid03, unless otherwise specified
Horizontal Datum	NAD83
Projection	UTM
Vertical Units	Meters (Orthometric, NAVD88)
Horizontal Units	Meters (UTM)
Deliverables	
Report of Survey	Text report (.pdf, .doc, or .odt format) that describes survey methods; results; contractor's accuracy assessments, including internal consistency and absolute accuracy; file formats; file-naming schemes; tiling schemes
Aircraft trajectories (SBET files)	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. *ASCII text or shapefile format*
All-return point cloud	List of all valid returns in LAS format. For each return: GPS week, GPS second, easting, northing, elevation, intensity, return#, return classification. May include additional attributes. No duplicate entries. GPS second shall be reported to the nearest microsecond (or better). Easting, northing, and elevation shall be reported to nearest 0.01 m (nearest 0.01 ft). Classification of returns shall be as complete as is feasible (including classes: 1. Unclassified, 2. Ground, 4. Vegetation, 6. Building, 7. Low Point (noise), 9. Water and 13. Bridges-Culverts), without avoidable return misclassification. Cloud file structure shall conform to 1/16th USGS 7.5-minute quadrangle (1.875 minute by 1.875 minute, see USGS 7.5' X 7.5' Quadrangle and Quarter-Quarter-Quad example below) tiles. 300 m. buffer should be acquired surrounding the AOI, no buffer needed in between tiles.

Ground (bare-earth) surface model	Digital elevation model of ground surface, interpolated using a triangulated irregular network from identified ground points and breaklines. To restrict data to ground elevations only, the LiDAR acquisition vendor must remove elevation points on vegetation, bridges, buildings, and other structures. The bare-earth DEM, with the minimum regular point spacing, no greater than 5 meters, allowed by the data in eastings and northings. Depressions (sinks), natural or man-made, are not to be filled (as in hydro-conditioning and hydro-enforcement). Elevation values must be floating point, not integer. Water bodies (ponds and lakes), wide streams and rivers ("double-line"), and other non-tidal water bodies as defined in Section III are to be hydro-flattened within the DEM. Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are larger than ~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. Development of hydro-flattening breaklines for streams less than 100' is encouraged. The methodology used for hydro-flattening is left at the discretion of the LiDAR vendor, use of the breaklines for DEM creation and classification is encouraged. Surface models shall have no tiling artifacts, no gaps and no artificial smoothing at tile boundaries. Areas outside survey boundary shall be coded as NoData. Internal voids (e.g., open water areas) may be coded as NoData.
Hydro-Flattening Breaklines	All breaklines developed for use in hydro-flattening shall be delivered as a 3D shapefile. Each shapefile will include properly formatted and accurate georeference information in the companion .prj file. Breakline elevations will use the same coordinate reference system (horizontal and vertical) and units as the LiDAR point delivery. Breakline delivery may be as a continuous layer or in tiles, at the discretion of the data producer. Tiled deliveries must edge-match seamlessly in both the horizontal and vertical. Hydro-flattening refers to DRAFT USGS Base LiDAR Specification Version 13. The intent of these breaklines is to accurately depict water feature surfaces having a continuous surface elevation.
Intensity image	Raster image of 1st-return intensity GeoTIFF, 1 m pixel size in 1/4th USGS 7.5-minute quadrangle (3.75 minute by 3.75 minute) tiles. Intensity images (return signal strength in native radiometric resolution for first return) should typically contain Dn values ranging from 0-100 or greater for 80% of areas with diverse land cover conditions. Intensity images must have the projection parameters defined.
Formal metadata	FGDC compliant, tile level metadata for tiled products and project level metadata for non-tiled datasets.

File Naming Convention. i.e. USGS Quarter Quad: "360125_3_C" Sample naming system:	USGS 7.5 min Quad: 360125  File Name Prefix: 360125_3_C

Usability

- Files shall conform to the specified File Naming Convention outlined above. (USGS Quad, Quarter-Quad and Quarter-Quarter-Quad Codes)
- Files shall have consistent internal formats
- Files may be gzip or zip compressed. Use of compression shall be uniform across a given data layer
- Contractor shall propose file-naming schemes and all details of file formats that are not specified here. Proposed naming schemes and formats must be approved by contracting agency
- Ancillary geographic feature data represented as vector data types (ESRI grids, shapefiles) shall have complete and correct associated projection files
- All files must be readable

Intellectual Property Rights

The contracting agency shall have unrestricted rights to all delivered reports and data. The contracting agency expects to place reports and data in the public domain.

2.2 Independent Quality Assurance and Quality Control Review

The State of Texas will establish contracts as needed, to perform independent quality assurance and control tasks in support of LiDAR data acquisition and processing. Prospective QA/QC providers should respond to the tasks outlined in the Table of Primary Project Tasks. Additional details will be defined in consultation with the program to develop a specific set of tasks and metrics for each project to be overseen by the QA/QC contractor.

The primary deliverable will be a report describing the QC provider's quality processes and results of LiDAR provider survey data. The report will provide quantitative and qualitative analysis of: accuracy assessments, including internal consistency and absolute accuracy as well as file formats; file-naming schemes; and tiling schemes. The report will be provided in *.pdf, .doc, or .odt* format.

Third Party Quality Assurance Quality Control Review	
Third Party QA QC Review Tasks	**Requirements**
Land Cover Categories and Check Point Selection	Taking input to confirm the proposed location of Check Points from the Texas Spatial Reference Center (TSRC), the independent quality control and assurance provider will categorize all land for areas of interest into one of five major land cover classes. A) bare-earth and low grass; b) high grass and crops; c) scrub, shrub woodlands; d) forest, dense trees; e)urban, built areas For each unit, The QA/QC contractor will direct independent survey contractors to select 20 or more check points in each of five land cover categories (10 of these will be reserved for final QC).
Check Point Surveys	The QA/QC contractor will conduct independent surveys of all check points to 5cm Local Network accuracy.
Documentation	The surveyor crew will mark each check point with a 60d nail or larger. The station ID number will be written on an adjacent above-ground stake within 1 foot of the referenced stake.
Orthometric Heights	The most recent NGS-approved geoid shall be used, if needed, to convert GPS ellipsoid heights into orthometric heights for each check point using NAVD88.
3-D Coordinate Files	The Surveyor will provide TWDB and the QA/QC team with all ASCII 3-D point files (x/y/z values) in UTM coordinates to 3 decimal places. The QA/QC team will share 50% of the surveyed check points with the LiDAR acquisition team for their internal QA/QC process.

LiDAR Accuracy Assessment	
100% RMSE Calculations	The QA/QC contractor will compute the vertical RMSE for 100% of the checkpoints evaluated.
95% RMSE Calculations	The QA/QC contractor will discard the least accurate 5% set of points (allowing 5% of the points to have unclean vegetation removal) and will re-compute the RMSE using the best 95% of the original check points. The QA/QC team will then provide both sets of RMSE calculations to the LiDAR acquisition team and to the TWDB.
RMSE by Land Cover Category	The QA/QC contractor will compute separate RMSEs for each different applicable land cover category.
Comparison with Accuracy Criteria	If the 95% RMSE calculation from the previous task passes the accuracy criteria (20cm or 25cm), the QA/QC team will prepare a LiDAR Accuracy Assessment Report indicating this fact. The LiDAR Accuracy Assessment Report will report the statistics, compared with the relevant accuracy standard, and include graphs of RMSEs by land cover categories. If the RMSE does not pass the accuracy criteria for bare-earth, notification to TWDB and the vendor should occur as soon as possible for corrective measures.
Error Assessments	A comprehensive set of error reporting will include System Verification, Laser Range Verification, IMU Verification, and Airborne GPS Verification. Additional Assessments will include Accuracy reports for each Land Cover type as well as Error Locations, Dates/Sensors and Accuracy of Breakline and Contour Data.
Deliverables	1) Control Point Survey Report 2) LiDAR Accuracy Assessment Report and 3) Final QA/QC Report delivered at the end of Phase IV, Product Development.

3.0 LiDAR Categories of the State and Areas of Interest (AOI)

The specifications for this Statement of Work are divided into four general categories: Urban, Coastal, Flood/Soils, and Forest. A generalized map of the state is provided for reference below and depicts the specifications generally intended to be applied in the respective areas.

Urban collections are established to allow for greater point densities that can support greater detail and additional derivative products and deliverables. Similarly, the Forest type is defined to support additional point densities to increase canopy penetration as well as potentially support studies of the canopy point class as a separate 3D feature. The coastal category is associated with specifications that are intended to provide greater accuracies in low relief areas subject to coastal storms and hurricanes. The Flood/Soils class is designed to allow for data that supports flood mapping as well as soil surveys.

All of the areas identified are expected to support detailed flood mapping. Far West Texas and the Panhandle are unspecified at this time due to the availability of technologies other than LiDAR to produce elevation data intended for inclusion into the state elevation data set. AOIs for LiDAR may be identified in this region as opportunities and requirements arise.

This Statement of Work establishes areas of interests defined by USGS quarter-quarter quadrangle grids.

AOIs are selected based on overlaying county boundaries, 12-digit hydrologic units from the National Watershed Boundary Dataset, and urban classes from the National Land Cover Dataset. The detailed definition of each quad unit may change due to local requirements and additional derivative products determined prior to the start of an AOI project. The final project grid will be based on project funding, coverage of desired hydrographic features, and flight planning efficiencies.

The potential project areas are defined by the contiguous grid cells defined in the individual area of interest map(s). The number of 16th quads is summarized in the text below the map for each AOI.

In the summary text, the predominant general category is also described. This should be used as a guide for defining work for individual AOIs. Respondents may select AOIs in any number and arrangement they see fit.

Texas LiDAR Categories