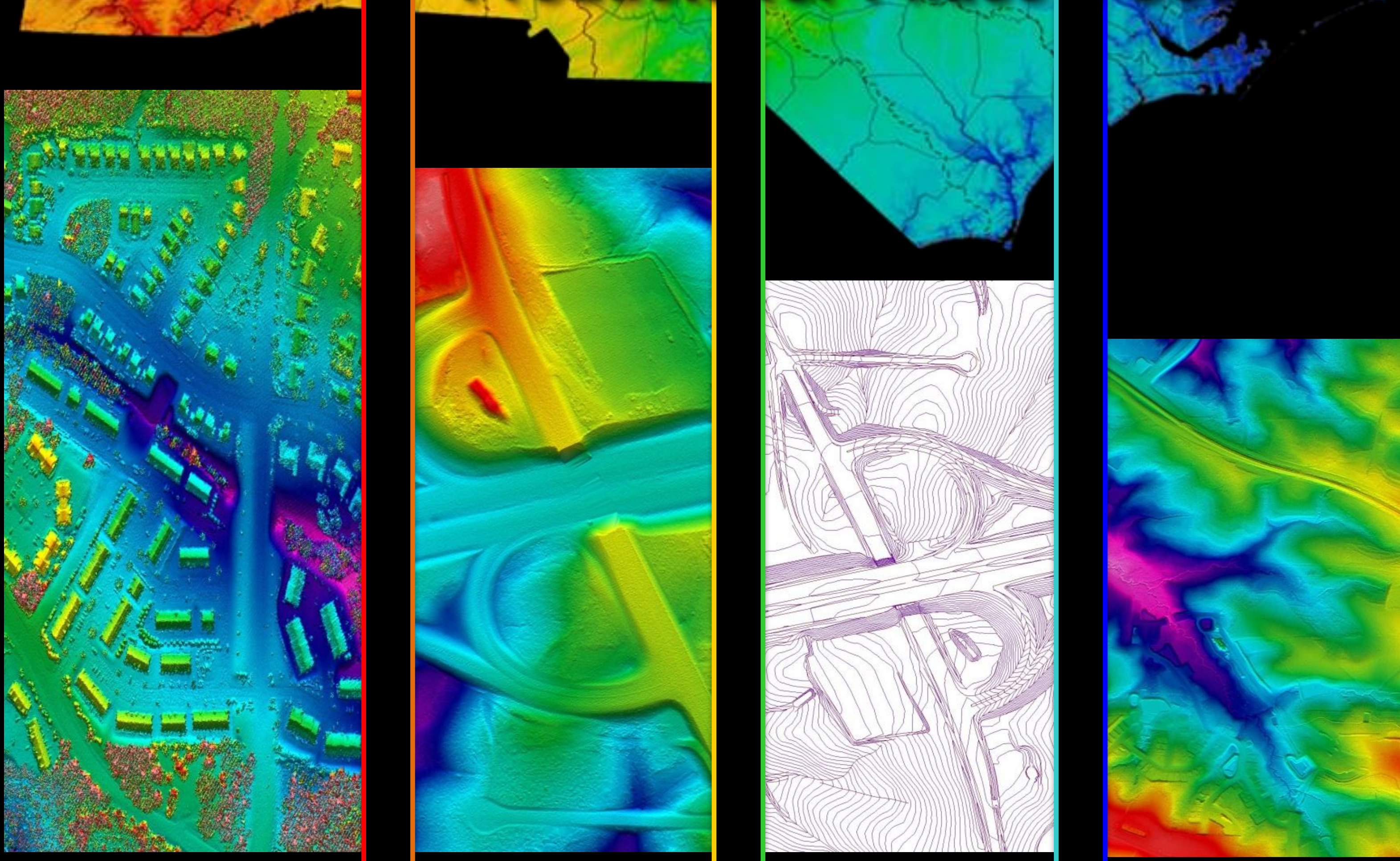
Technical Proposal

Contract No. 286-0000-23 ESP

Delivery Order No. 59

LiDAR Acquisition and Associated Products for Phase 2 Counties



January 22, 2014

Submitted By:
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Submitted To:

NORTH CAROLINA
Cooperating Technical State
FEMA'S COOPERATING TECHNICAL PARTNER

ESP Associates, P.A.

January 22, 2014

Mr. John Dorman
North Carolina Geospatial & Technology Management Office
4105 Reedy Creek Road
Raleigh, NC 27607

RE: Delivery Order No. 59
LiDAR Acquisition and Associated Products for Phase 2 Counties
Technical Proposal - Revised

Mr. Dorman:

Based upon the request for additional software recommendations on January 21, 2014 please find the attached revised Technical Proposal for Delivery Order No. 59 last dated January 21, 2014. The following is a summary of the revisions:

- Added a recommendation for usage of LP360 software in visualizing, analyzing, and reviewing submitted data as part of this Delivery Order.

In addition, our business proposal has been revised and will be submitted separately. If you have any questions or need any additional information, please do not hesitate to call me at 919-678-1070.

Sincerely,
ESP Associates, P.A.

Will Draper, GISP, CFM
Project Manager

David M. Key, P.E., CFM
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cc: Hope Morgan | NCFMP
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Overview

The State of North Carolina Floodplain Mapping Program (NCFMP) has provided ESP Associates, P.A. (ESP) a Request for Delivery Order (RFDO) to perform LiDAR data collection, processing, and generation of Hydro DEM raster products for the Phase 2 area in the eastern region of North Carolina. In addition the State has requested optional value added products, which are addressed separately in this document. ESP has been asked to submit written technical and business proposals in response to the request, compliant with our IDIQ contract No. 286-0000-23 ESP.

Scope of Work

Under this Delivery Order ESP will perform data collection, processing, and delivery of LiDAR for 20 counties totaling approximately 13,000 square miles. The baseline data for delivery will cover the entire area shown in Figure 1 plus a 100 meter buffer outside the area boundary. The data will meet the requirements for the current USGS Quality Level 2 (QL2) LiDAR Specification, where the Fundamental Vertical Accuracy (FVA) at the 95% confidence level is 18.13 centimeters (cm) with a RMSEz of 9.25 cm. The counties included with this delivery are shown in Table 1 and in Figure 1.

Table 1: Counties included with this delivery order.

2014 North Carolina LiDAR Collection			
Bladen	Franklin	Nash	Sampson
Brunswick	Greene	New Hanover	Warren
Columbus	Halifax	Northampton	Wayne
Duplin	Johnston	Pender	Wilson
Edgecombe	Lenoir	Robeson	Vance

Task 1: LiDAR Data Acquisition

Task 1 will include the necessary subtasks for the acquisition of LiDAR data. The following is a summary of the scope of services for Task 1.

Task 1a: Planning, Coordination, Flight Operations, and Specifications:

Overview

The ESP Team will be acquiring, processing, and delivering the requested LiDAR data and the derivative products. For Task 1, the LiDAR data will be acquired by the ESP Team members Merrick & Company, Surdex Corporation, and The Atlantic Group. The data will be collected to meet 2 points per square meter with nominal post spacing of 0.7 meters. All data will include multi-return and intensity values. Data collected will support a 9.25 cm (3.36 inches) RMSEz and 18.13 cm FVA based on NDEP guidelines.

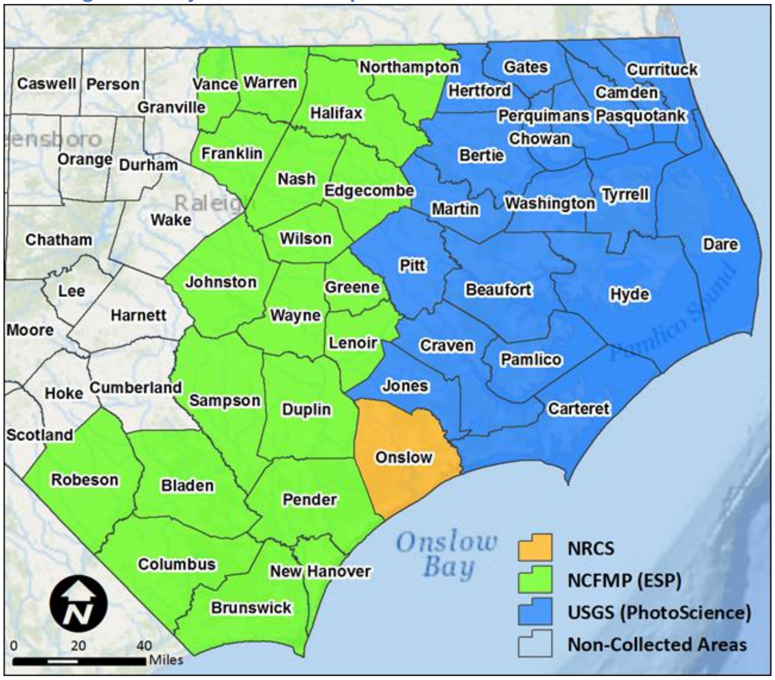
Kickoff Meeting

Once this Technical Proposal has been accepted by the State, a kickoff meeting will be held with the ESP Team, the State, and other relevant stakeholders. This meeting will be held before the data collection to reach consensus on the data collection flight plan, acquisition plan parameters, reporting mechanisms, communication plan, and identification of the project's Points of Contact (POC). This meeting will also establish the protocol for ground condition issues such as heavy rain, flooding, leaf out, or other unforeseeable circumstances.

Adjacent Contractor Coordination

It is understood that additional North Carolina Counties will also be under LiDAR Data Acquisition concurrently with this delivery order via the USGS and NRCS as shown in Figure 1. ESP will develop a coordination and communication plan with the teams responsible for that data collection. This plan will be submitted to and approved by the State for implementation.

Figure 1: Adjacent LiDAR acquisition for the winter 2014 season.



Flight Operations Management

To ensure an efficient and effective collection schedule, ESP has assigned Flight Operations management for aerial LiDAR acquisition to the Surdex Corporation. Surdex will be the primary POC between all ESP team subcontractors. Their responsibilities will include block layout designation, daily ongoing flight plan management, team coordination, issue mitigation, coordination with Military Operation Areas (MOAs), and daily progress reporting to ESP.

Project Boundary and Buffer

ESP has submitted a project boundary digitally to the State for evaluation and approval. ESP understands that buffer requirement based on North Carolina Specifications for LiDAR Base Mapping is currently 2,000 feet. ESP believes this is unnecessary for evaluation of the data seam between the USGS and NRCS collection areas and would like to propose a smaller buffer to facilitate cost savings for the State. In addition, these adjacent collection areas (based on USGS specifications) are collecting a 100 meter buffer of overlap to the full extent of the proposed 5000 feet x 5000 feet statewide tile scheme. Figure 2 shows the LiDAR tiles that will be captured and processed by ESP for delivery to the State. Figure 3, illustrates the LiDAR tiles and the 100 meter buffer that will be implemented relative to the political boundaries for the counties ESP will be performing LiDAR Acquisition. Please note that ESP requests that the State reduce the project boundary buffer from 2,000 feet to 100 meters. This recommendation is also summarized in Appendix A, Requested Technical Specification Exemptions.

Figure 2: LiDAR tile scheme.

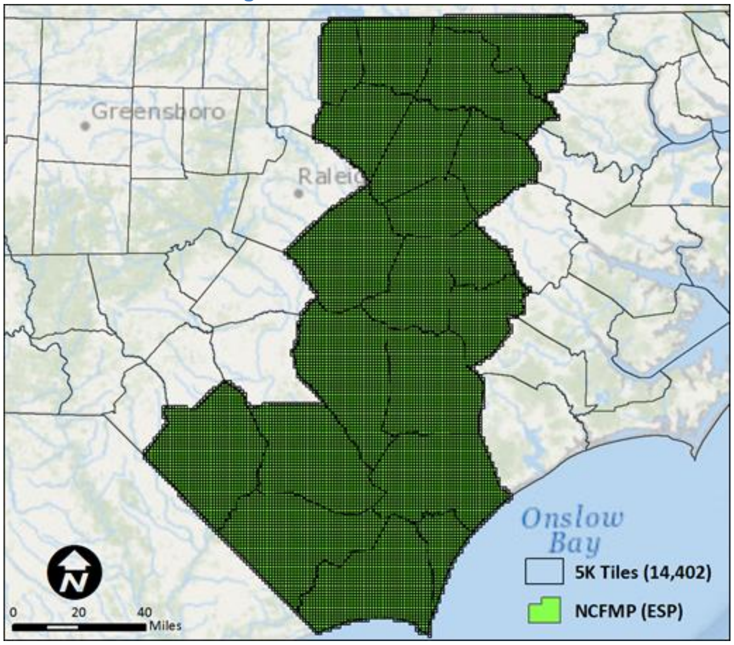
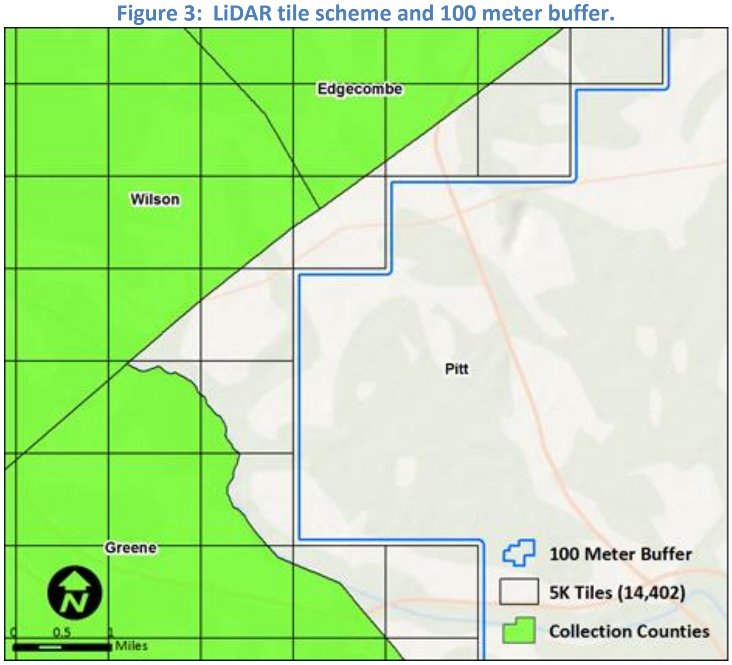


Figure 3: LiDAR tile scheme and 100 meter buffer.



Task 1b: Data Acquisition

Acquisition Specifications

All LiDAR systems on the project meet/exceed the minimum specifications for the North Carolina and the USGS. If requested by the State, ESP will provide Sensor Certifications for each piece of hardware. Included in Appendix B of this Technical Proposal, is a listing of all hardware and software that are planned for use within this delivery order. Table 2 details the specific acquisition specifications that will be followed as part of this delivery order.

Table 2: Acquisition specification parameters for LiDAR data.

Parameter	Specification
Boundary buffer	≥ 100 meters beyond tile boundaries
Nominal Post Spacing (NPS)	≤ 0.7 meters, including overlap
Signal returns	First, last, and one additional intermediate return
Intensity	Each return pulse
Overlap	≥ 20%
Maximum line length	≤ 50km (31 miles)
Maximum Scan Angle	≤40 Degrees
Maximum line time	≤ 20 minutes
Clustering	Regular grid of with a cell size of 2*NPS ≥ 90% of cells will contain at least one LiDAR point
Vertical accuracy	RMSEz = 9.25cm FVA = 18.13 cm at 95% CI CVA = 26.9cm at 95th percentile SVA = 26.9cm at 95th percentile

Acquisition Conditions

The LiDAR acquisition team will adhere to the following environmental guidelines as shown in Table 3. Any request to deviate from this plan due to unforeseen circumstances will be clearly and immediately communicated to the State for written approval as/if necessary.

Table 3: Acquisition condition parameters for LiDAR data.

Parameter	Specification
Acquisition Window	Winter/Spring 2014
	April 15, 2014 Acquisition Cut-Off
Atmospheric Conditions	Cloud and fog free
	Snow free (Light, undrafted snow may be acceptable)
	No unusual flooding or inundation
	Leaf-off
Tidal Conditions	Predicted Mean Low Water (MLW) +/- 2 hours

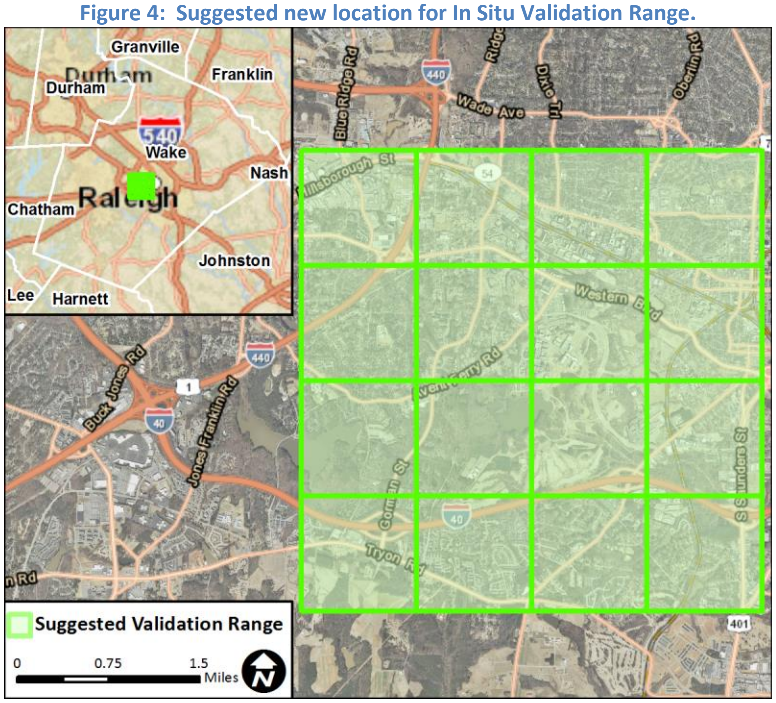
Flightline Overlap

ESP is aware of the 50% overlap requirement based on the NC Specifications for LiDAR Base Mapping. This specification was based on older sensor technologies, which could not achieve the Ground Sample Distance (GSD) requirements without this amount of overlap. Using State-of-the-Art LiDAR sensors on this project, ESP will achieve the required GSD with less than 50% overlap. ESP's submitted flight plan will contain a 20% flight line overlap that reduces the number of flight hours required to collect the data while still achieving the base (QL2) specification. The ESP Team's approach will optimize the mission plan (flight profile) to benefit project cost and schedule. Please note that ESP requests that the State reduce the flight line overlap requirement from 50% to 20%. This recommendation is also summarized in Appendix A, Requested Technical Specification Exemptions.

***In Situ* Validation Range**

ESP is aware of the North Carolina *In Situ* Validation Range Requirement. The purpose of this requirement is to validate the LiDAR sensor in a working environment to prove that it can correctly and consistently acquire data that meet the specifications of the project. It is understood that this requirement can be waived by the contracting officer. ESP has evaluated the current location of the *In Situ* Range and would like to recommend a new location to evaluate the sensors prior to commencement of data collection. Based on lessons learned from previous missions, ESP recommends a new location that contains better morphologic makeup for robustly testing conditions that exacerbate potential sensor anomalies, most specifically regarding areas with dramatic reflectance variability including: water, opaque, and highly reflective surfaces. In addition, this area is more central to the State and may be more efficient for future phases of LiDAR acquisition. The proposed validation range is illustrated in Figure 4. If the State approves this area, ESP will collect sufficient ground control for the purposes of the sensor calibration and validation. Please note that ESP requests that the State accept an alternate location for the *In Situ* Validation Range. This will also be included in Appendix A, Requested Technical Specification Exemptions.

Figure 4: Suggested new location for In Situ Validation Range.



Daily Calibration Flights (Pre/Post Mission)

ESP is aware of the State's LiDAR specification regarding the pre-post flight collection of calibration flights over established control to boresight LiDAR sensors. Based on ESP's experience, this requirement is based on older calibration procedures that lacked methods for bundle adjustment, a procedure commonly used today to meet and exceed project accuracy. ESP's bundle adjustment approach is a more robust approach that will better address the ≤7 cm relative accuracy within swath overlap (between adjacent swaths) and the FVA of 18.13 cm at the 95% confidence level accuracy requirements. This process will be further detailed in Task 1d, Calibration. Please note that ESP requests that the State waive the pre-post flight calibration requirement and accept our new calibration methodology. This will also be included in Appendix A, Requested Technical Specification Exemptions.

Data Acquisition Plan

The data collection plan has been broken into a total of 45 small sub-blocks shown in Figure 5, which limit flight line length to 31 miles. This equates to a maximum online time of ≤ 20 minutes to reduce any potential inertial drift (improves inertial precision). In addition, each block contains a cross flight collection, shown in Figure 6, which will be used for the bundle adjustment calibration procedure.

Figure 5: Sub-block layout for LiDAR collection.

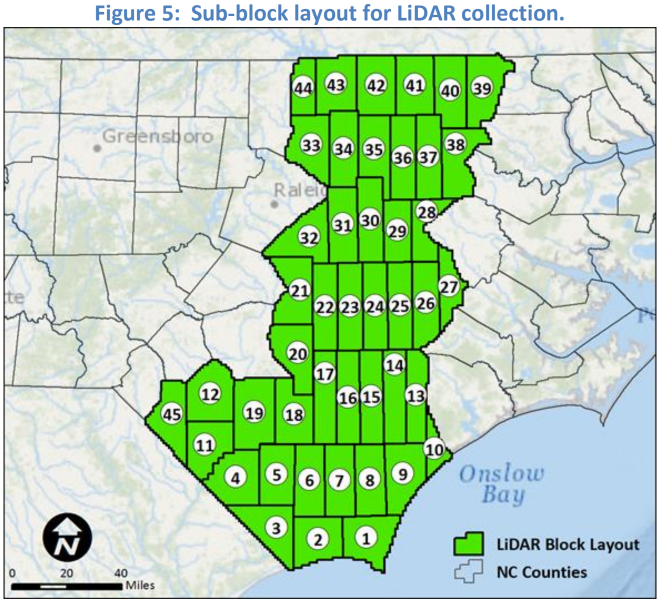
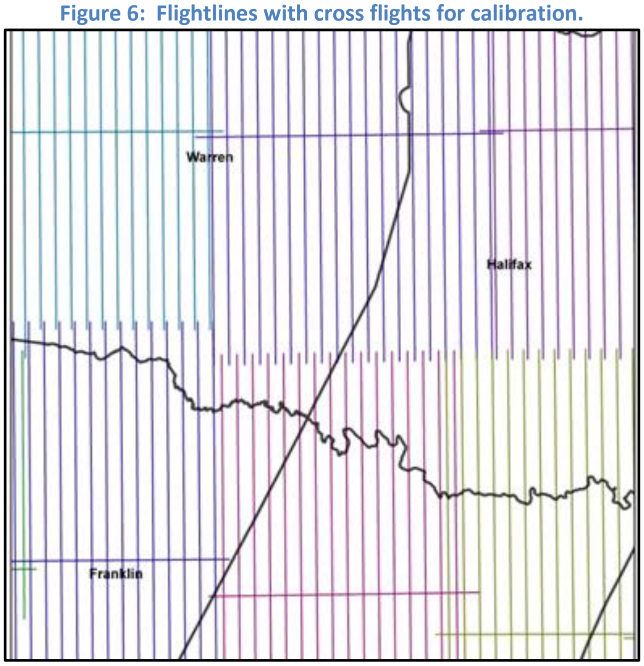


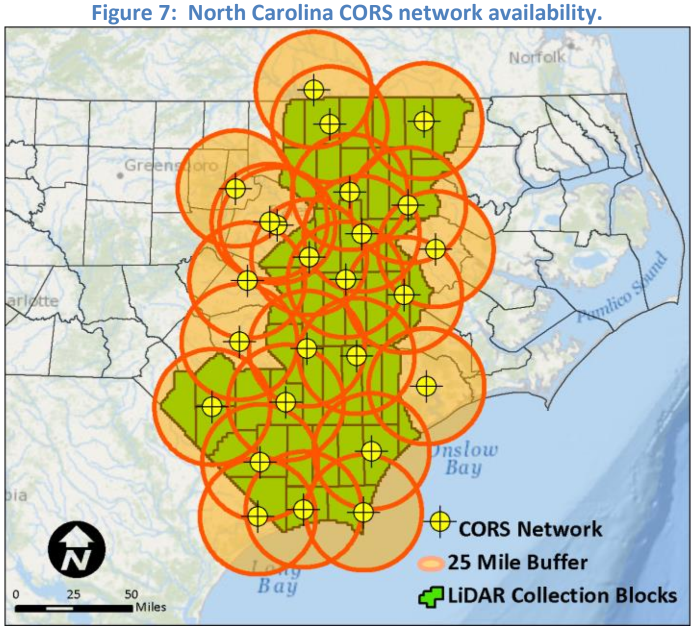
Figure 6: Flightlines with cross flights for calibration.



GPS Coverage Considerations

As illustrated in Figure 7, roving base stations will not be required due to the dense Continuously Operating Reference Station (CORS) network in the State of North Carolina. This figure portrays the 1-second frequency CORS stations with a 25 mile radius. As can be seen, the requirement to maintain less than 50 km (31 miles) from each base station is easily satisfied using the existing network.

Figure 7: North Carolina CORS network availability.



MOAs and Restricted Areas

There are several Military Operations Areas (MOAs) and restricted airspaces that will require close coordination. This includes areas such as Roanoke Rapids Air Force Station, Seymour Johnson Air Force Base, and US Army Sunny Point. All of ESP's team members have faced the challenges of MOAs, Restricted, and Temporary Flight Restricted (TFR) airspaces in previous projects, including in prior years of the North Carolina Statewide Ortho-imagery program. Coordination with most MOAs requires contacting the proper authorities to arrange to either capture data in off-hours or be granted non-interfering access during "hot" hours. In many cases, data acquisition must occur when the range is "cold". Since LiDAR can take place during evening hours, as opposed to imagery acquisition during daylight hours, the option remains to acquire data outside of the operating hours of the MOA, which is typically between sunrise and sunset.

Restricted and TFR areas are another matter and will require help from the State to determine a suitable solution. In all cases, ESP will present detailed flight plans to the required authorities to both pursue a solution with each and keep them fully informed. Each crew's Chief Pilot will coordinate these issues in advance with the State, the appropriate authorities and keep all aircrews informed of the proper approach. In most cases, the pilot will take over direct communication leading up to the day of flight.

Data Coverage Verification

Validation of field data is a time-critical process. Since re-mobilizations have significant financial and schedule impacts, each collection team will ensure all data have been completely and accurately acquired before leaving the project site. Data is downloaded from the aircraft's on-board computers and backed up on field hard drives immediately after the completion of each mission. The data will be sent overnight to the office and verified for:

1) Visual inspection - Coverage to project extents, appropriate GSD, cloud shadows, data irregularities (e.g., unusual data voids, extreme vertical/horizontal misalignments, and other anomalies).
2) Quality inspection - GPS and IMU data are processed to a preliminary stage; sufficient to complete a quantitative location and quality analysis of the data collected. Dilution of Precision (DOP), combined separation and other quality GPS/Inertial metrics reviewed to ensure trajectory solutions will support final accuracies. LAS files are generated to visually compare against the project's boundary. For any data gaps or other identified data problems, new flight lines are generated to cover the problem areas and sent electronically to the sensor operator on-site.

The entire data coverage verification process is typically completed within 12 to 24 hours for each mission flown.

Task 1c: Ground Control

Supplemental Project Survey Ground Control

ESP will collect approximately 700 well-distributed GPS survey control points to supplement airborne GPS accuracy. Field procedures consistent with the National Geodetic Survey *Guidelines for Real Time GNSS Networks* will be followed. These procedures include making redundant occupations under different satellite configurations and field conditions for each point. No control panels will be placed as part of this effort. This control will be used to facilitate calibration of LiDAR flightlines/blocks, perform mean adjustment, and test final fundamental accuracy of the data. The vertical accuracy checkpoints will adhere to the following guidelines:

1) Located only in open terrain, where there is a high probability that the sensor will have detected the ground surface without influence from surrounding vegetation.
2) On flat or uniformly sloping terrain at least five (5) meters away from any breakline where there is a change in slope.
3) Checkpoint accuracy shall satisfy a Local Network accuracy of 5 cm at the 95% confidence level. Accuracy will be tested using National Standard for Spatial Data Accuracy guidelines.
4) Photos will be taken at each control point location.

Task 1d: Calibration

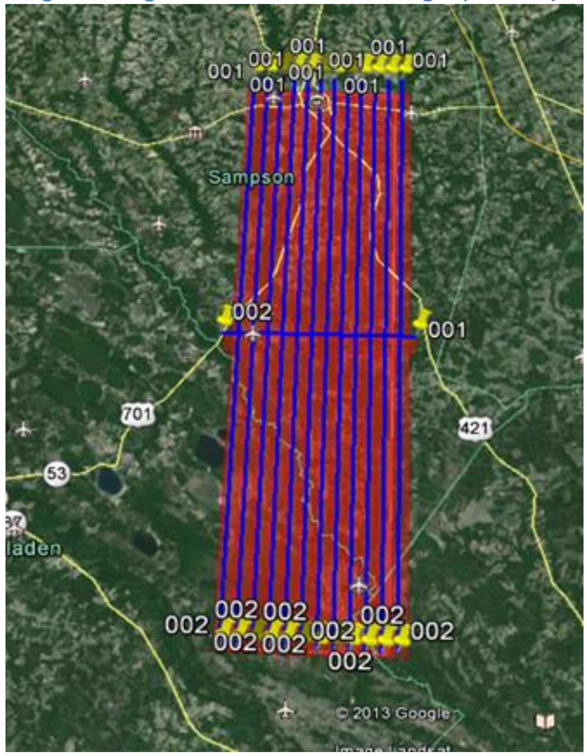
Overview

ESP proposes to utilize a modern and robust data calibration procedure which has been adopted by our team as common practice when producing robustly calibrated LiDAR datasets. For this delivery order ESP has chosen Merrick & Company to perform calibration of all LiDAR missions. This decision is based on Merrick's experience with large geographic extents and prior performance with this data specification. In addition, it minimizes potential disparities that can occur when performed separately. In addition, Merrick is licensed in the State of North Carolina to certify the final accuracy.

Comparison

In contrast to older procedures using pre and post mission calibration flights, this procedure alleviates this requirement by adding cross-flights (cross ties) to each flight block providing for a higher level relationship to bundle adjust all flightlines as a whole rather than making the assumption that the pre-post calibration will hold throughout the duration of a single flight mission. In essence, this breaks the process down to small blocks of adjustment which are subsequently adjusted to the larger area via the project control network. A single sub-block is illustrated in Figure 8.

Figure 8: Flightline block with a cross-flight (cross tie).



Project Calibration Accuracy Specifications

Final calibrated data will meet USGS specifications to support a 9.25 cm fundamental and subsequent 1 foot contour accuracy. Detailed testing methods and reports will be compliant with USGS specifications and can be found in the Quality Assurance/Quality Control Plan Task 8 of this document.

Procedure

The process will ensure all LiDAR acquisition missions were carried out in a manner conducive to post-processing an accurate data set. Significant attention will be given to GPS baseline distances and GPS satellite constellation geometry and outages during the trajectory processing. Verification that proper Airborne GPS (AGPS) surveying techniques were followed including: pre and post mission static initializations and review of In-air IMU alignments, if performed, both before and after on-site collection to ensure proper self-calibration of the IMU accelerometers and gyros were achieved.

Relative Accuracy Calibration (Data precision)

A minimum of one cross-flight is planned throughout each project block area across all flightlines and over roadways where possible. The cross-flight provides a common control surface used to remove any vertical discrepancies in the LiDAR data between flightlines and aids in the bundle adjustment process with review of the roll, pitch, heading (omega, phi, kappa). The cross-flight is critical to ensure flight line ties across the sub-blocks and the entire project area. The areas of overlap between flightlines are used to calibrate (aka boresight) the LiDAR point cloud to achieve proper flight line to flight line alignment in all 6 degrees of freedom. This includes adjustment of IMU and scanner-related variables such as roll, x, y, z, pitch, heading, and timing interval (calibration range bias by return) Each LiDAR mission flown is independently reviewed, bundle adjusted (boresighted), and/if necessary, improved by a hands-on bore-sight refinement in the office.

Fundamental Accuracy Verification (Absolute Accuracy)
Once this relative accuracy adjustment is complete, the data will be adjusted to the high order GPS calibration control to achieve a zero mean bias for fundamental accuracy computation, verification, and reporting. Please note the final accuracy testing procedures, methods and reporting are covered in the QA/QC section of this proposal and are compliant with USGS specifications.

Task 2: Classification of LiDAR Points

Task 2 will include the classification of all LiDAR points as captured in Task 1. The following is a summary of the technical approach and scope of services for Task 2.

Task 2a: Algorithm Development and Classification

Overview
The LiDAR filtering process encompasses a series of automated and manual steps to classify the boresighted point cloud dataset. Each project represents unique characteristics in terms of cultural features (urbanized vs. rural areas), terrain type and vegetation coverage. These characteristics are thoroughly evaluated at the onset of the project to ensure that the appropriate automated filters are applied and that subsequent manual filtering yields correctly classified data. Data is most often classified by ground and "unclassified", but specific project applications can include a wide variety of classifications including but not limited to buildings, vegetation, water, etc.

ESP recommends the latest American Society for Photogrammetry and Remote Sensing's (ASPRS) Standard LiDAR Point Classes scheme (LAS Specification Version 1.3 Record Type 3) for this project. ESP is recommending an expanded classification scheme to the State to improve downstream data value for potential future value added options such as remote sensing to update the building database, impervious surface mapping, and road classifications. The ESP Team will classify the LiDAR point cloud in accordance with the following classifications as shown in Table 4.

Table 4: Proposed classification scheme.

Class	Description
1	Processed Unclassified
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Buildings (Automated)
7	Noise (High/Low)
9	Water (Hydro Cleaned Areas)
12	Flight Line Overlap

Auto Filter (Classification)
A filtering macro(s), which may contain one or more filtering algorithms, will be developed and executed to derive LAS files separated into the different classification groups as defined in the ASPRS classification table. The macros are tested in several portions of the project area to verify the appropriateness of the filters. Often, there is a combination of several filter macros that optimize the filtering based on the unique characteristics of the project. Automatic filtering generally yields a ground surface that is 85-90% valid, so additional editing (hand filtering) is required to produce a more robust ground surface.

Task 2b: Manual Edits and Corrections

Re-classification Editing

The next task associated with LiDAR classification is to manually re-classify (or hand-filter) "noise" and other features that may remain in the ground classification after the auto filtering. A cross-section of the post-auto-filtered surface is viewed to assist in the reclassification of non-ground data artifacts. Certain features such as berms, hilltops, cliffs and other features may have been aggressively auto-filtered and points will need to be re-classified into the ground classification. The following is an example of re-classification of the non-ground points (elevated features) that need to be excluded from the true ground surface. Figure 9 illustrates a small building that was incorrectly auto-filtered. Data in the colorized TIN orthographic and point profile view displays non-ground (Unclassified, class 1) in grey and ground in brown/tan (Class 2) which needs to be manually re-classified. Figure 10, shows the result of the re-classification using hand-filtering.

Figure 9: Incorrect classification of ground features.

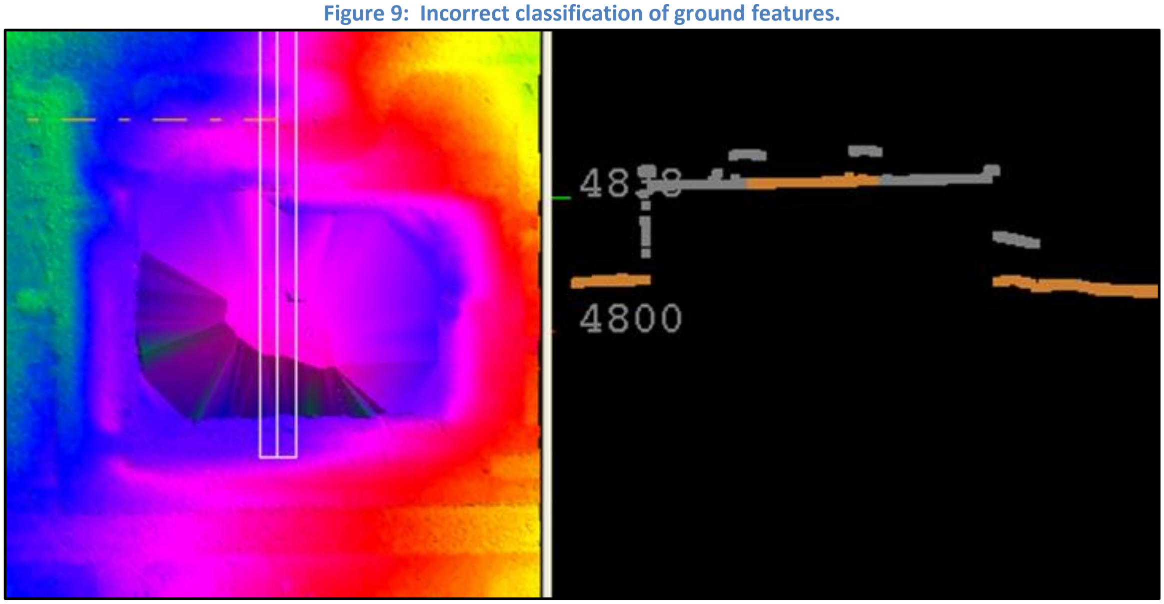
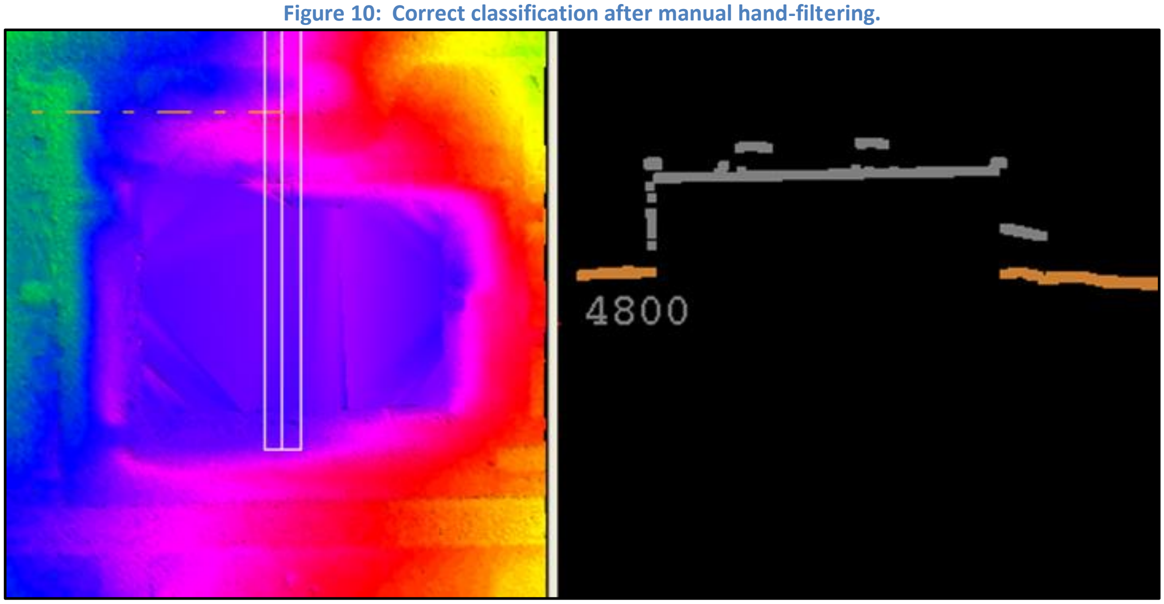


Figure 10: Correct classification after manual hand-filtering.



The ESP team will use a combination of automated and semi-automated routines to classify buildings and vegetation. We expect that the classified buildings will meet a filtering criterion in the range of 90-95%. While every effort will be made to optimize this result no further cleanup of the building feature class is planned for this project, so some residual points will exist in this data class.

Fundamental Accuracy Check

Once manual editing has been completed and quality checked, a Control Report is generated to validate that the accuracy of the ground surface is within the defined fundamental accuracy specifications. Each surveyed ground check point is again compared to the LiDAR surface by interpolating an elevation from a Triangulated Irregular Network (TIN) of the surface. This derived report provides an in-depth statistical report, including an RMSE of the vertical errors; a primary component in most accuracy standards and a statistically valid assessment of the fundamental accuracy of the final ground surface. An example of the Control Report is displayed in Figure 11.

Figure 11: Example of Classification Control Report.

ID	X	Y	TIN Coverage	Z of Control	Z from LiDAR	Z Error	Min. Z	Median Z
521	3287458.89	1587815.38	Yes	4624.21	4624.13	-0.08	4624.1	4624.12
522	3312753.64	1593936.68	Yes	4631.67	4631.75	0.08	4631.62	4631.7
523	3308369.72	1597340.58	Yes	4700.94	4700.81	-0.13	4700.69	4700.73
524	3297720.73	1604545.5	Yes	4821.27	4821.44	0.17	4821.4	4821.43
525	3271753.11	1608308.54	Yes	5095.96	5096	0.04	5095.97	5096
526	3272146.39	1604505.92	Yes	4945.57	4945.61	0.04	4945.54	4945.61
527	3276989.81	1604380.62	Yes	4865.07	4865.17	0.1	4865.07	4865.18
528	3277393.62	1587253.8	Yes	4645.08	4645.15	0.07	4645.09	4645.11
529	3287990.72	1587380.81	Yes	4617.37	4617.28	-0.09	4617.17	4617.24
530	3252027.11	1607083.87	Yes	4894.84	4894.8	-0.04	4894.66	4894.8

Task 3: Development of DEMs in ESRI Grid Format

Task 3 will include the generation of 3D breaklines for the purpose of hydro-flattening the terrain. The following is a summary of the technical approach and scope of services for Task 3.

Task 3a: Hydro-Breakline Generation

Overview

Prior to the DEM generation, breaklines will be collected to further define (hydro-flatten) the terrain and enhance the accuracy of the LiDAR DEMs. Breaklines for this project consist of two primary categories; water bodies ≥ 2 acres and rivers ≥ 100 feet in width. Industry accepted practice will be utilized to compile hydrographic breaklines in 2D directly from the LiDAR bare earth data. Color cycles in the TIN model provide a clear indication of where breaklines are to be collected. During this step, polygon /polyline vertices are created at highly accurate horizontal/vertical coordinates providing for a hydro-flattened DEM. Figure 12 illustrates a raw (bare earth) DEM and Figure 13 illustrates a hydro-flattened DEM with water points reclassified and excluded from the TIN generation.

Figure 12: Raw bare earth DEM, not hydro-flattened.

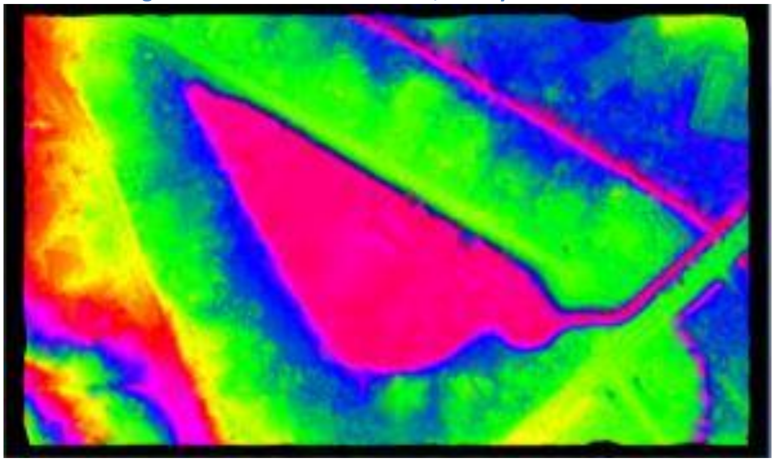
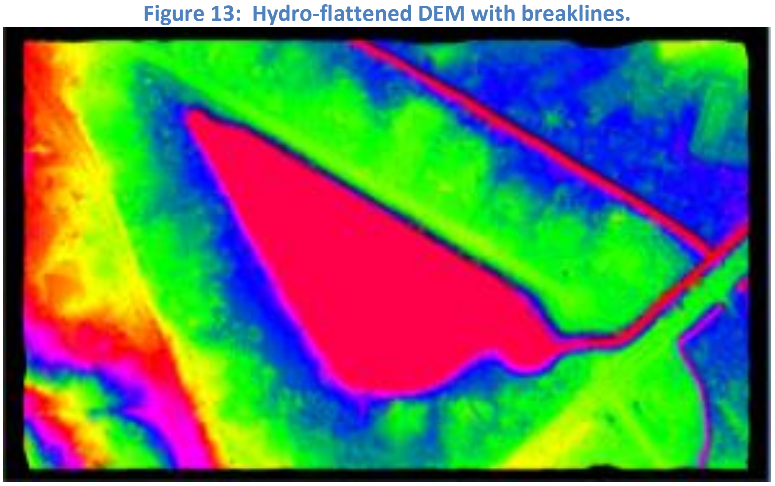


Figure 13: Hydro-flattened DEM with breaklines.



The collection of breaklines in a 2D environment provides significant advantages over "LiDARgrammetry" or "Photogrammetric" approaches, which often introduce optical disparity when compared to the LiDAR DEM as they are separate processes with no direct correlation (Coupling) to the LiDAR data. Both of these processes rely on stereoscopic procedures which can manifest vertical errors above/below the LiDAR terrain surface and have horizontal errors relative to water body and conveyance embankments (Toe). With the ESP team approach, breakline elevations/positions are extracted directly from the LiDAR bare earth data eliminating the risk of a horizontal/vertical miss-match to the DEM.

Hydro-Flattening Specifications

Hydro-flattening breaklines will be compiled based on the guidelines and principles outlined in the NGP-USGS LiDAR Base Specification Version 1.0. The following Hydro Flattening Requirements will be adhered to for this project.

Inland Ponds and Lakes:

- 2-acre or greater surface area (~350' diameter for a round pond)
- Flat and level water bodies (single elevation for every bank vertex defining a given water body).
- The entire water surface edge must be at or just below the immediately surrounding terrain.

- Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, should be treated as rivers.

Inland Rivers*:*

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

Islands

- Permanent Islands ≥1 acre shall be delineated

Non-Tidal Boundary Waters*:*

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

Tidal Waters*:*

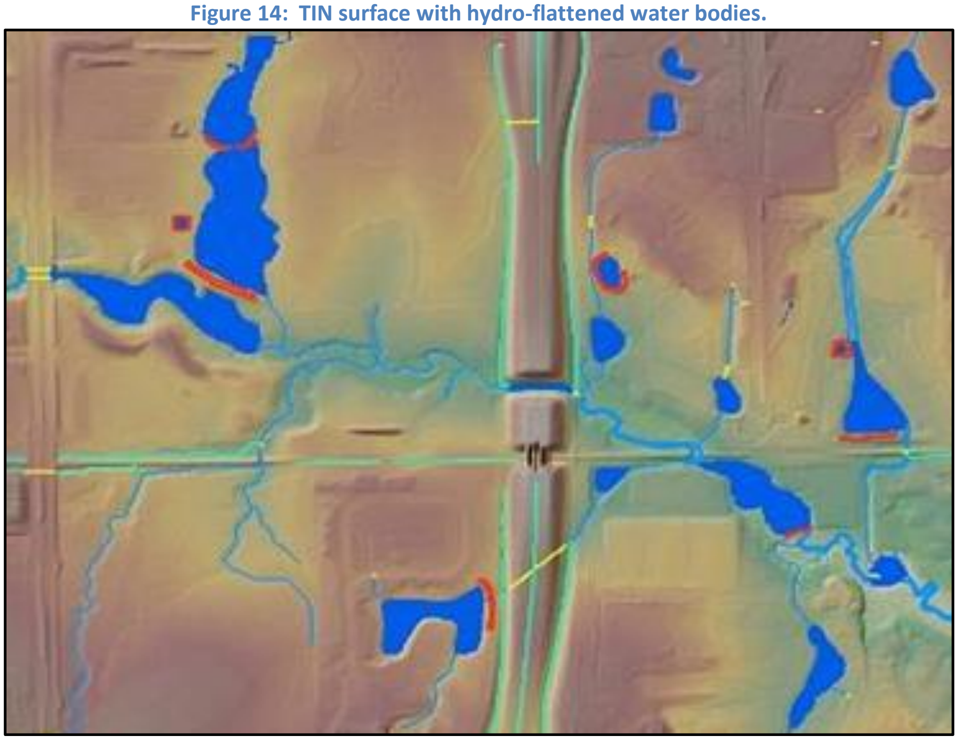
- Water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any significant water body that is affected by tidal variations.
- Tidal variations over the course of a collection, and between different collections, will result in discontinuities along shorelines. This is considered normal and these “anomalies” should be retained. The final DEM should represent as much ground as the collected data permits.
- Variations in water surface elevation resulting in tidal variations during a collection should NOT be removed or adjusted, as this requires either the removal of ground points or the introduction of unmeasured ground into the DEM. The USGS NGP priority is on the ground surface, and accepts the unavoidable irregularities in water surface.
- 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.
- Coordination should be concurrent with the USGS and NRCS project areas to ensure unintended disparities are not created along the coastline.

Adjacent Contractor Coordination

ESP understands the States desire to achieve a consistent and homogenous statewide LiDAR data repository. ESP is also aware of the LiDAR terrain and bathymetric data collection of the coastline and is concerned that this may/may not represent a disparity in how these areas are treated. At the onset of the project a coordination meeting with the State ESP, USGS, and NRCS should be scheduled to discuss a cohesive approach along the data seam with regard to LiDAR terrain accuracy, coordinating control efforts, and tie in of hydro breaklines. This coordination will prevent potential schedule delays and provide the state with a consistent statewide product.

Water Bodies Procedure (Lakes and Ponds)
Using a TIN with elevation color ramp and/or contours to illustrate the lowest elevation, the LiDAR technician will measure the lowest LiDAR point elevation at or slightly below the water body. The breakline is set (Z- locked) and compiled (traced) to the appropriate elevation horizontally based on the TIN color contrast and/or displayed real-time contour display. Once the polygon is complete (closed) the interior points are reclassified to water (class 9). This step is repeated for each water body breakline that is being collected. Islands within water bodies shall be compiled at the lake elevation and interior points retained as ground. Hydro-flattened water bodies are illustrated in Figure 14.

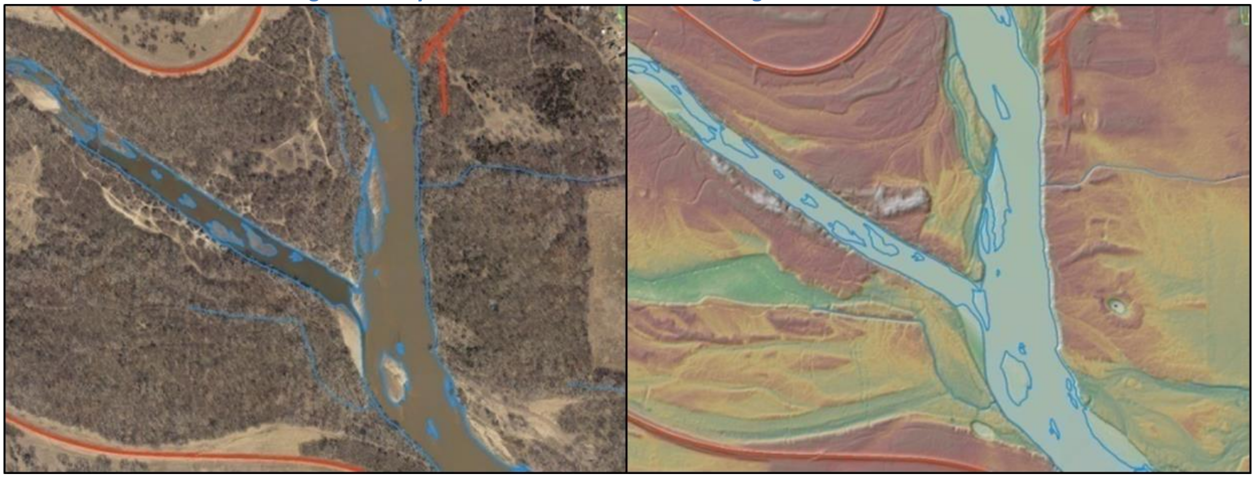
Figure 14: TIN surface with hydro-flattened water bodies.



Please note ESP has reviewed and tested the existing hydro layer. ESP may use them as general guidance in this process, but it is understood that they will not facilitate a high level of accuracy given the resolution the QL2 LiDAR data.

Water Lines Procedure (Rivers and Streams)
Double line drain features (Rivers) will be enforced monotonically (have downhill directionality) for linear hydrographic features. Hydrographic breakline collection is always completed in a downhill direction. Any vertices compiled will always be lower in elevation from the previous point; if not, it retains the same elevation as the previous point. River breaklines are compiled on one side of the hydro feature first. Next the second side of the river is compiled with the elevation of the opposing side (perpendicular to) being applied to enforce monotonic behavior. Islands within river shall be compiled separately and reflect the opposing banks monotonic behavior. Figures 15 below illustrates the affect that using islands along with river breaklines will have among a terrain model that has been hydro-flattened.

Figure 15: Hydro-flattened terrain model along a river with islands.



Breakline Tile Seams at Project Boundary

Non-Tidal Areas

These areas will compiled to the 2014 LiDAR tile boundary and treated the same as their representative features with the following exceptions:

1) Rivers will be broken at the tile edge with elevations representing their final monotonic value(s).
2) Water bodies will be closed at the tile seam with their representative (Z- locked) elevation.
3) In both instances partial Islands may exist and will be closed at the tile seam to reflect appropriate elevations as described in the previous processes.

Tidal Areas

Due to the USGS coastline LiDAR and bathymetric acquisition, close coordination with the USGS, NRCS, and State will be necessary to ensure a cohesive approach to delineating the coastline and other tidally influenced areas.

Final DEM Grid Generation

Final breaklines and LiDAR bare earth points will be utilized to produce the final hydro-flattened terrain as a TIN. This model will be used to produce DEMs to quality control the 3D breaklines. Based on ESP's understanding, the State has requested that no DEM Raster products be delivered as part of this task. Please note that this is also documented in Appendix B, Requested Technical Specification Exemptions.

Task 4: Terrain Datasets by County

ESP will compile ESRI Terrain Datasets for each county in the Phase 2 LiDAR collection area. The following is a summary of the technical approach and scope of services for Task 4.

Task 4a: Terrain Dataset Compilation

Process Overview

Each Countywide Terrain will be stored in an individual File Geodatabase format in Arc version 10.0 or later. The Terrains will be loaded with the processed LiDAR .las file bare earth points, which have been converted to multipoint features. These multipoint features will be stored as the Surface Feature Type (SFType) "mass points" and will be embedded into the Terrain. The most current county boundary from the State will be used as SFType "hard clip". Any breaklines developed as part of the project will also be included within the Terrain and will have the appropriate SFType assigned based on the type of input feature. The Pyramid Type will be set to the Z Tolerance setting and the Pyramid Properties and Levels will be calculated using the Calculate Pyramid Properties dialog within the ESRI Terrain development tool.

Task 5: Intensity Images

ESP will compile intensity images for each LiDAR tile processed. The following is a summary of the technical approach and scope of services for Task 5.

Task 5a: Intensity Image Generation

Process Overview

Once the LiDAR point cloud has been classified and has passed both the internal and independent quality control, LiDAR intensity images will be generated. Each of these images will be generated using the classified LiDAR points and their associated intensity returns with the exception of Class 7 Noise and Class 12 Flight Line Overlap. The intensity image will be exported in grayscale, 8-bit, GeoTIFF format using the same tile scheme as the other LiDAR deliverables. For the purposes of this proposal it is assumed the 8-bit format will be an Unsigned 8-bit depth with 256 available unique values from 0 to 255. The GeoTIFF intensity image will have a raster cell size of 10 feet.

Task 6: Metadata

ESP will develop FGDC compliant metadata. The following is a summary of the technical approach and scope of services for Task 6.

Task 6a: Metadata Generation

Overview

ESP will generate metadata to all appropriate deliverables that are FGDC compliant and in XML format. Once metadata file will be generated for each project, lift, and tiled deliverable product group. For the purposes of this technical proposal a tiled deliverable product group refers to the classified point could data, hydro-flattened DEMs, ESRI Terrain datasets, and intensity images. It is not anticipated that individual metadata files for each tile will be required. All deliverable metadata files will pass the USGS metadata parser with no errors or warnings. Please note that newer version of ESRI releases contain additional superfluous lines and text that may generate errors in the USGS parser that are listed as a Severity of "0". ESP will limit the number of these instances where possible.

Task 7: Preparation of Project Reports

ESP will prepare the appropriate project reports as detailed in the North Carolina Specifications for LiDAR Base Mapping and be available to attend the necessary meetings. The following is a summary of the technical approach and scope of services for Task 7.

Task 7a: Project Reporting

Overview

ESP will attend and prepare for weekly meetings throughout the life cycle of the project. At each of these meetings, ESP will deliver a weekly status report, detailing acquisition, calibration, processing, and any other current actions of the project. In addition, ESP will prepare the following list of reports, as detailed in the North Carolina Specifications for LiDAR Base Mapping, and each of these reports will be delivered, including the appropriate professional seals, within 5 days of the completion of the task to the North Carolina GTM SharePoint site: Collection Report, Survey Report, Processing Report, and Quality Assurance/Quality Control (QA/QC) Report.

The Collection Report will detail the mission planning and flight plan logs associated with the Acquisition and Data Collection phase of the project, also known as Task 1 of this Technical Proposal. A Survey Report will be prepared, along with North Carolina Professional Land Surveyor (NCPLS) certification and seal that will detail the collection of control and reference points used for the calibration and QA/QC of the acquired LiDAR data. The Processing Report will provide detailed information on the calibration, classification, and product generations procedures including methodology used for breakline extraction and hydro-flattening. During the entire course of the project there will be an ongoing QAQC component for each phase and subsequent deliverable. All of this quality control information will be formatted into a QAQC Report that will provide a detail analysis, accuracy assessment and validation of the LiDAR point data (absolute, within and between swaths), bare earth surface (absolute), and the other deliverable products stated within this Technical Proposal.

Task 8: Quality Assurance / Quality Control Plan

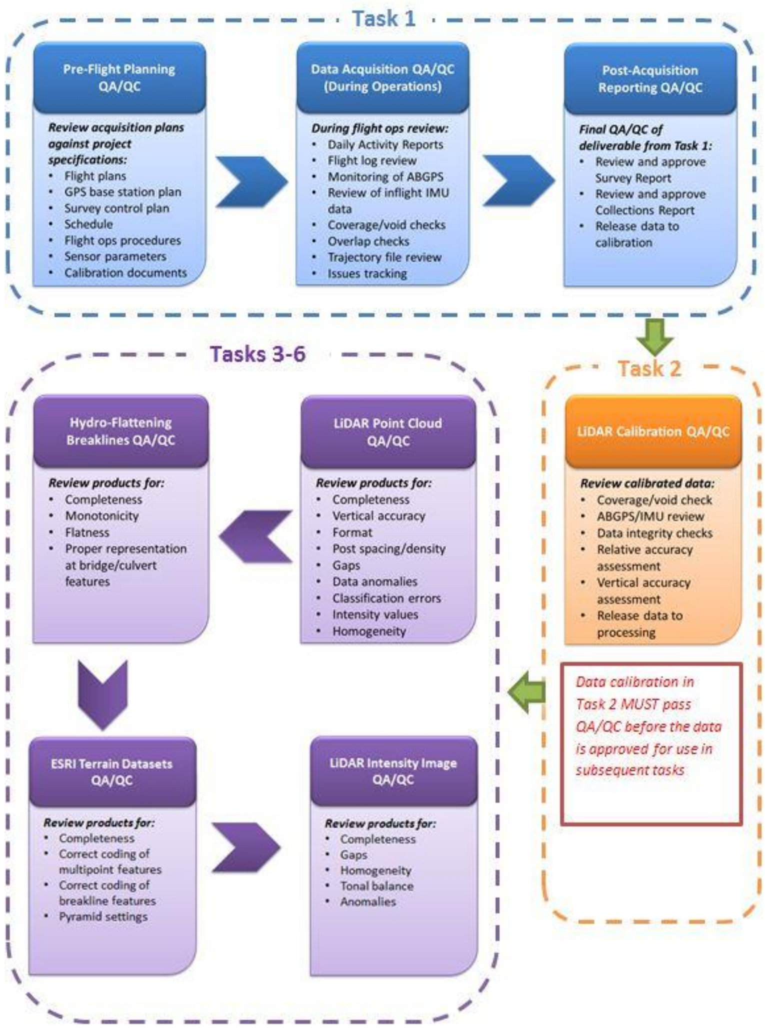
ESP will implement a Quality Assurance/Quality Control (QA/QC) Plan to ensure that each phase of the project is adhering to the aforementioned specifications, and accuracy requirements. The following is a summary of the technical approach and scope of services for Task 8.

Process Overview

The ESP QA/QC workflow is designed with built-in redundancy, taking into account human-error and the lessons learned by team members from years of providing similar services. ESP understands that the responsibility of ensuring quality rests with every individual working on the project and has structured the QA/QC workflow to include checks for each step of the planning, acquisition, and production tasks.

ESP will utilize a series of documents and checklists to monitor and control the QA/QC processes for this project. Checklists will be filled out by the individuals conducting the QA/QC and then reviewed by senior technicians so that a record exists of the completed of QA/QC tasks. The overall QA/QC workflow developed by ESP for this program is outlined in Figure 16, below.

Figure 16: QA/QC Plan workflow.



QA/QC Feedback Loop

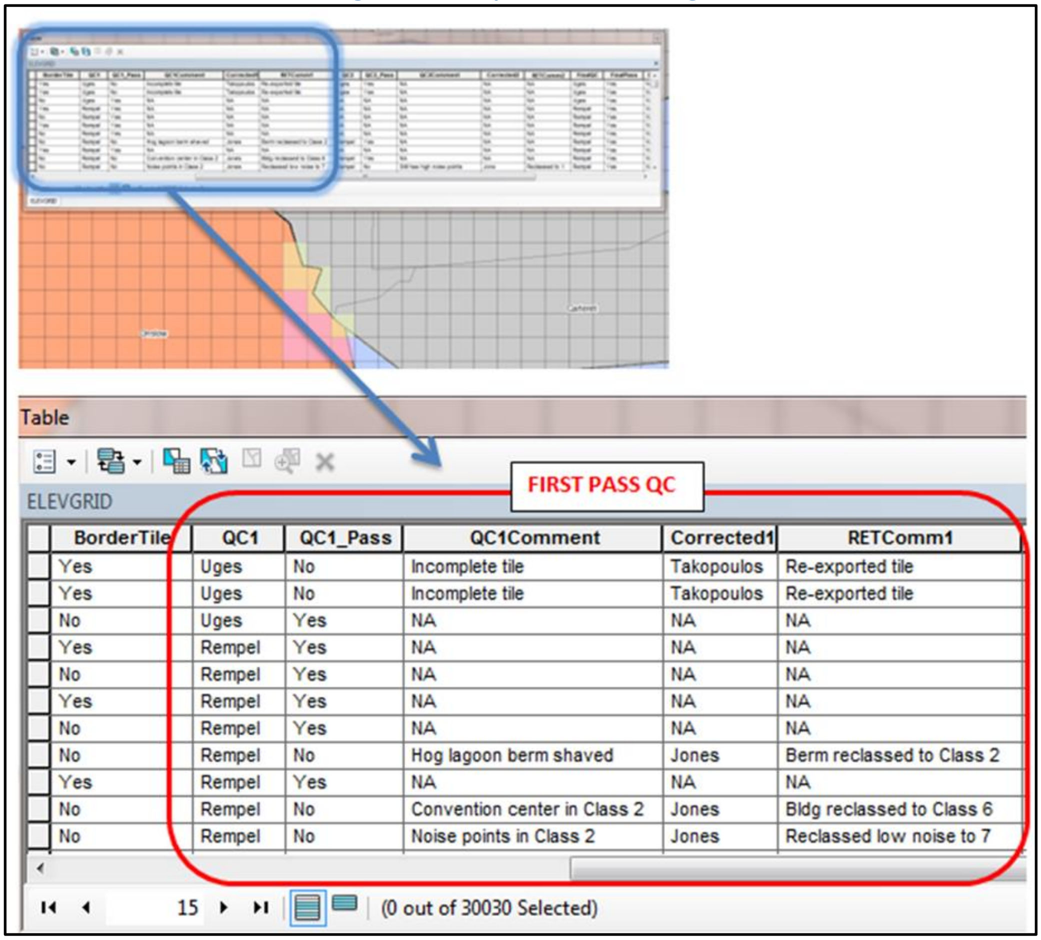
ESP's QA/QC workflow incorporates a feedback system by which the errors found are tracked in a concise manner. All rejections are reviewed again after resubmittal by the production team to ensure that the QA/QC call was addressed, and to ensure that no additional errors were erroneously introduced as a result of the fix. This documentation will also be used as input to continually improve the workflow.

The documentation and review of products that consist of multiple tiles (such as the LiDAR LAS) will be tracked through the use of the project tile layout by modifying the attribute table. This approach will allow ESP to track the following during each QA/QC review:

1) Border tiles (to ensure coordination with the other team and boundary coverage);
2) Issues identified;
3) Individuals conducting the QA/QC;
4) Individuals making corrections;
5) Number of iterations to solve an issue;
6) Final approval.

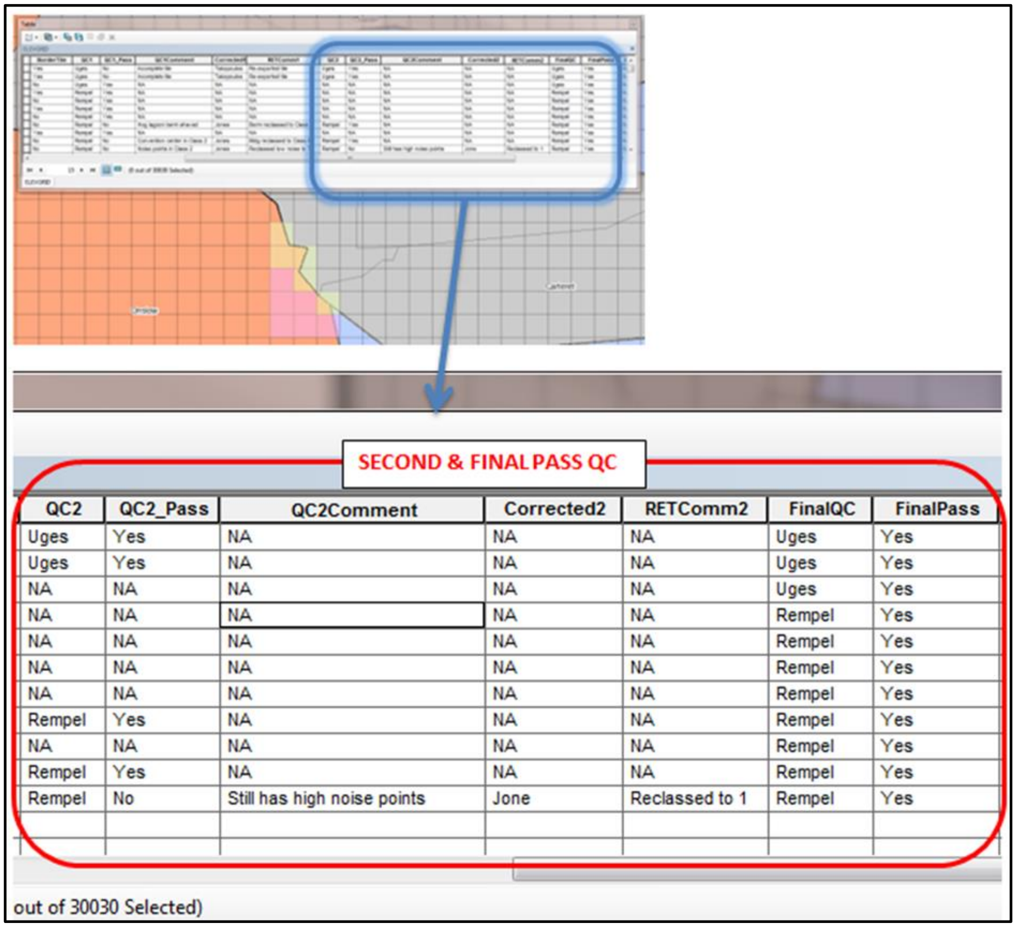
Figures 17 and 18 demonstrate this tracking system using a sample attribute table based on the State tile layout.

Figure 17: First pass QA/QC tracking.



BorderTile	QC1	QC1_Pass	QC1Comment	Corrected1	RETComm1
Yes	Uges	No	Incomplete tile	Takopoulos	Re-exported tile
Yes	Uges	No	Incomplete tile	Takopoulos	Re-exported tile
No	Uges	Yes	NA	NA	NA
Yes	Rempel	Yes	NA	NA	NA
No	Rempel	Yes	NA	NA	NA
Yes	Rempel	Yes	NA	NA	NA
No	Rempel	Yes	NA	NA	NA
No	Rempel	No	Hog lagoon berm shaved	Jones	Berm reclassed to Class 2
Yes	Rempel	Yes	NA	NA	NA
No	Rempel	No	Convention center in Class 2	Jones	Bldg reclassed to Class 6
No	Rempel	No	Noise points in Class 2	Jones	Reclassed low noise to 7

Figure 18: Second and final pass QA/QC tracking.



QC2	QC2_Pass	QC2Comment	Corrected2	RETComm2	FinalQC	FinalPass
Uges	Yes	NA	NA	NA	Uges	Yes
Uges	Yes	NA	NA	NA	Uges	Yes
NA	NA	NA	NA	NA	Uges	Yes
NA	NA	NA	NA	NA	Rempel	Yes
NA	NA	NA	NA	NA	Rempel	Yes
NA	NA	NA	NA	NA	Rempel	Yes
NA	NA	NA	NA	NA	Rempel	Yes
Rempel	Yes	NA	NA	NA	Rempel	Yes
NA	NA	NA	NA	NA	Rempel	Yes
Rempel	Yes	NA	NA	NA	Rempel	Yes
Rempel	No	Still has high noise points	Jone	Reclassed to 1	Rempel	Yes

By tracking the QA/QC, issues, and corrections ESP will be able to document quality metrics such as:

1) Percentage of tiles passing the first pass QC ("First Time Right")
2) Types and distribution of issues
3) Trends and/or systemic errors

As a product of this process, any information of import will be incorporated into the "Lessons Learned" portion of the relevant report (Collection Report, Processing Report, etc.) and will be used to continually improve QA/QC methodology.

Task 8a: LiDAR Data Acquisition QA/QC

Overview

The QA/QC workflow for Task 8a is broken into 3 distinct phases to ensure that quality is monitored throughout the task:

1) Pre-flight Planning QA/QC;
2) Data Acquisition QA/QC;
3) Post-Data Acquisition Reporting QA/QC.

Pre-flight Planning QA/QC

Flight operations for data acquisition will not commence until the team has reviewed and obtained approval for the data acquisition plan for the Phase II counties that will be collected. To facilitate the

QA/QC, ESP has established guidelines for pre-flight documentation that shall be submitted to the Quality Control Manager for approval. This documentation consists of an Operations Plan along with the associated files covering sensor calibration information, ground survey control plan, flight plans, planned GPS base stations, and project boundaries.

ESP's internal guidelines for pre-flight documentation are derived from the baseline requirements outlined in Table 4.1 in FEMA's *Procedure Memorandum No. 61 – Standards for LiDAR and Other High Quality Digital Topography* (FEMA's PM-61). ESP has appended these baseline requirements with additional content that will be included in the **Operations Plan**. Figure 17 outlines this additional content alongside the FEMA PM-61 baseline requirements for ease of review:

Table 5: Minimum content for Operations Plan.

FEMA PM-61 Baseline Requirements	ESP Additional Content
• **Planned flightlines** • **Planned GPS stations Planned control** • **Planned airport locations** • **Calibration plans** • **Quality procedures for flight crew (project-related for pilot and operator)** • **Planned scanset (sensor settings and altitude)** • **Type of aircraft** • **Procedure for tracking, executing, and checking reflights** • **Considerations for terrain, cover, and weather in project**	• **Communications matrix (survey & flight crews, QA/QC and flight managers)** • **Contingency plan** • **Anticipated airspace constraints** • **Sensor calibration information** • **Project boundaries and buffers** • **Data transfer procedure** • **Daily reporting procedure** • **Intensity gain settings**

ESP's Quality Control Manager will ensure that the **Operations Plan** and any associated files are reviewed to verify that the project design meets or exceeds the technical requirements of the project and that the proper controls are established prior to data acquisition commencing. Upon review of the initial submittal, the Quality Control Manager shall hold a feedback meeting with the data acquisition team to discuss any potential issues with the plan and to provide feedback. Once any issues and/or feedback have been addressed, the plan will be submitted to the NCFMP Program Manager.

If the NCFMP Program Manager requires any revision to the plan, the revision will be incorporated and the plan resubmitted for approval prior to data acquisition activities. As part of this approval process, the project boundary and associated buffer shall be submitted as a digital file for final approval and verification.

Data Acquisition QA/QC

During Operations

QA/QC during data acquisition operations begins in the field with the personnel executing the task. These personnel represent the first line of defense against potential issues and will follow in-field QA/QC procedures on a daily basis to ensure that each day of collection meets the specifications of the project. In-field QA/QC procedures include (but are not limited to):

1) Pre-flight aircraft and equipment checklists;
2) Pre- and post-flight initializations of ABGPS;
3) Review of sensor logs for each flight
4) Monitoring of ABGPS and sensor during flight;

5) Review of in-air IMU alignments;
6) Initial completeness check of each flight's data prior to shipping to office.

Once each day's collection is shipped overnight to the office, it immediately undergoes the QA/QC outlined in the Data Coverage Verification section of this proposal.

ESP understands that strong coordination between flight crews, survey crews, and managers is critical to the success of this phase and has established internal daily reporting requirements for data acquisition operations. This ensures that data acquisition and quality managers are continuously aware of any potential issues that could arise. These requirements include delivering flight logs, Activity Reports, sensor logs, and trajectory files for review on a daily basis. The flight logs to be used by the team shall include information that will allow for the initial verification of the flights against plan and to ensure that a level of redundancy is present in the QA/QC process.

Internal Daily Activity Reports will be consolidated as needed to compile an Acquisition Report (acquisition status) that will be distributed to the project stakeholders by the ESP PM. The content and frequency of the Acquisition Report will be determined by the project kick off meeting. At a minimum, ESP shall include the following items in the report:

1) ESRI shapefile representing the geographic extent of the acquired data during the relevant reporting period
2) Graphic of the above to facilitate presentation of the status to non-ESRI users
3) Anticipated progress for the next reporting period
4) Any issues encountered
5) Progress against the baseline schedule

ESP has established minimum content for flight logs that will be used for the project. This minimum content is derived from the baseline requirements outlined in Table 4.2 in FEMA's Procedure Memorandum No. 61 – Standards for LiDAR and Other High Quality Digital Topography (FEMA's PM-61). ESP has appended these baseline requirements with additional content that will be included in the flight logs. Table 6 outlines this additional content alongside the FEMA PM-61 baseline requirements for ease of review.

Table 6: Minimum flight log content.

FEMA PM-61 Baseline Requirements	ESP Additional Content
• **Job # / name** • **Lift #** • **Block or AOI designator** • **Date** • **Aircraft tail number, type** • **Flight line, line #, direction, start/stop, altitude, scan angle/rate, speed, conditions, comments** • **Pilot name** • **Operator name** • **Intensity settings** • **Laser pulse rate** • **Mirror rate** • **Field of view** • **Airport of operations** • **GPS base station names/numbers**	• **Sensor name/type** • **Sensor serial number**

During the data acquisition phase, the Quality Control Manager will coordinate closely with the Aerial Acquisition Manager to continuously monitor operations and review all internal and external reports for content and compliance with the project specifications.

Post-Acquisition Data QA/QC

The post-acquisition data QA/QC begins immediately upon receipt of a day's flight data. In order to identify potential issues as early as possible, the goal is to review and approve each day's flight within 24 hours or less. This ensures that potential re-flights are identified prior to the aerial assets demobilizing from any particular area. This phase of the project QA/QC workflow is conducted using visual and qualitative inspection methods designed to verify that each day's collection will support the specifications and final accuracies of the project. They are conducted as follows:

1) Visual inspections – will verify coverage, resolution of LiDAR, data irregularities (e.g., unusual data voids, extreme vertical/horizontal misalignments, and other anomalies).
2) Quality inspections - GPS and IMU data are processed to a preliminary stage; sufficient to complete a quantitative location and quality analysis of the data collected. Dilution of Precision (DOP), combined separation and other quality GPS/Inertial metrics reviewed to ensure trajectory solutions will support final accuracies. LAS files are generated to visually compare against the project's boundary. For any data gaps or other identified data problems, new flightlines are generated to cover the problem areas and sent electronically to the sensor operator on-site.

In accordance with the NC LiDAR Standard and internal processes used by the team, the following detailed QA/QC steps illustrated in Table 7 are taken to verify that the data is ready for production and that there are no issues with the data that would trigger a re-flight:

Table 7: Post-Acquisition QA/QC Matrix.

QA/QC Step	Comments	Corresponding Standard/Specification
1. Data completeness	Deliverable media is readable; all files for flight are present, no gross gaps, cross flights are present	Internal
2. Check against flight plan	Trajectory files are reviewed to ensure flight plan was followed	Internal
3. Flight parameters	Sensor settings and flight reflect the approved project design	Internal
4. Data coverage	Data covers planned collection; areas along project boundary and 100' buffer are adequately covered	Contractual
5. Data voids	Do not exceed 4*Nominal Pulse Spacing (NPS) except where caused by water bodies, low reflectivity, or is filled in by another swath/lift	NC LiDAR Standard Section 5.01.4
6. GPS & IMU	Reviewed to ensure proper operation/coverage/quality (includes base stations)	Internal and NC LiDAR Standards, Sections 5.02.4 and 6
7. Density	Review of density to verify proper operation of sensors and flight execution. Nominal pulse spacing (NPS) is 0.7 meter or better	Contractual
8. Intensity	Intensity values are present and consistent in range	NC LiDAR Standard Section 5.01.2

QA/QC Step	Comments	Corresponding Standard/Specification
9. Overlap	Overlap between adjacent lines is 20% or better	*See exemption request*
10. Signal returns	Multiple returns are present	NC LiDAR Standard Section 5.01.1

Post-Acquisition Reporting QA/QC

The final QA/QC step for Task 8a is the review of the final reports from this task (which includes the Collections Report and Survey Report) to provide a final verification of the executed task against plan. This ensures that the reports meet the minimum content requirements of the NC LiDAR Standards as well as the baseline requirements in Table 4.2 in FEMA's PM-61.

For the Collections Report, ESP has appended these baseline requirements with additional content that will be included in the report. Table 8 outlines this additional content alongside the FEMA PM-61and NC LiDAR Standard requirements for ease of review:

Table 8: Post Collections Report minimum content.

FEMA PM-61 Baseline Requirements	NC LiDAR Standard	ESP Additional Content
• **GPS base station information:** ○ **Base station name** ○ **Latitude/Longitude (ddd-mm-ss.sss)** ○ **Base height (Ellipsoidal meters)** ○ **Maximum Position Dilution of Precision PDOP** • **Map of locations** • **GPS/IMU processing summary:** ○ **Max Horizontal GPS Variance (cm)** ○ **Max Vertical GPS Variance (cm)** ○ **Notes on GPS quality (High, Good, etc.)** ○ **GPS separation plot** ○ **GPS altitude plot** ○ **PDOP plot** ○ **Plot of GPS distance from base station/s** • **Coverage – verification of data coverage** • **Flights:** • **As-flown trajectories** • **Calibration lines** • **Flight logs (incorporated as an Appendix)** • **Control – control and base station layouts** • **Data verification/QC:** • **Description of data verification/QC process** • **Results of the verification and QC steps**	• Mission planning detail • Flight logs	• **Project overview** • **Description and resolution of issues encountered (if applicable)** • **Lessons learned** • **Recommendations for future projects**

The Survey Report shall be reviewed and quality controlled to ensure that it meets the requirements outlined in Sections 9.01 and 9.03 of the NC LiDAR Standard and internal quality requirements:

1) The report shall be prepared under the supervision of a North Carolina Professional Land Surveyor and certified and sealed by the surveyor in responsible charge in accordance with North Carolina Surveying Law N.C. G.S. 89C.
2) The report shall contain details outlining the collection of the control and reference points used for calibration and QA/QC.
3) Survey points are verified to ensure that they were collected per standard operating procedures for LiDAR control.

The Quality Control and Acquisition Managers will review the Collection Report and Survey Report for content and accuracy prior to the submittal of the reports to the NCFMP Program Manager.

Task 8b: LiDAR Calibration QA/QC

Process Overview

The QA/QC workflow for Task 8b of this project consists of verifying the results of the data calibration via visual inspection and accuracy testing (positional and relative). Because the LiDAR calibration process adjusts the data, some of the initial quality checks from the data acquisition phase (Task 1) are repeated. The quality checks that are repeated after calibration include:

1) Data coverage and void check;
2) Review of ABGPS and IMU data;
3) Data integrity checks (to verify no change in returns present, intensity quality, etc.).

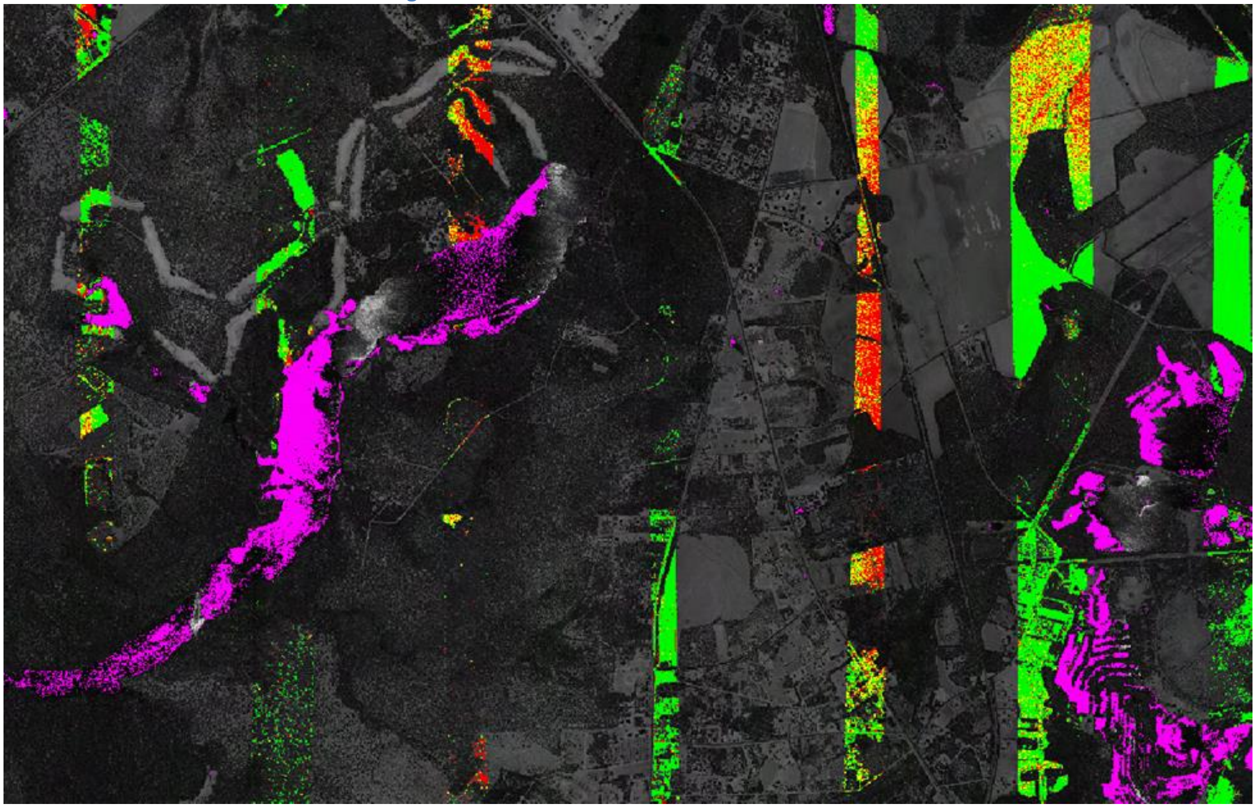
Relative Accuracy Assessment

Relative accuracy within individual swath and within swath overlap will be calculated to ensure that the data meets or exceeds the threshold required to obtain a Fundamental Vertical Accuracy (FVA) of 18.13 cm and ≤9.25cm RMSEz. To assess the relative accuracy and quality of the calibration DZ orthos will be run, holding the vertical threshold for relative accuracy within the swath overlaps to ≤ 5cm. This exceeds the threshold outlined in Section 5.01.11 of the NC LiDAR Standard and ensures that the required FVA threshold is met.

DZ ortho-images are produced based on the relative height differences between adjoining LiDAR swaths in overlapping areas. These height differences are colorized, allowing the QC technician to detect potential vertical accuracy issues. As the technician reviews the DZ ortho-images, any elevation differences of significance are reviewed to determine if the source of the error is a calibration issue.

Figure 21 is an example of a DZ check of ~7 adjoining swaths of LiDAR data. The color ramp of green to red indicates the level of elevation difference within the overlap area of adjoining lines; with green being a good match within specification and red indicating areas where the reviewer needs to take a close look. In the below example, voids in the LiDAR have been colored purple, allowing for the immediate identification of unacceptable data gaps. The gaps visible in the below example are acceptable gaps caused by water bodies. The software also automatically ignores data voids caused by water when calculating metrics such as data density.

Figure 19: DZ ortho check for LiDAR calibration.



Vertical Accuracy Assessment

During Task 2, only the FVA will be calculated to assess vertical accuracy as FVA is determined by a comparison against vertical checkpoints in open terrain and the LiDAR data have not undergone automated and manual classification yet. Supplemental and Consolidated Vertical Accuracy (SVA and CVA) will be assessed on the final deliverable LiDAR data once the point classification has been conducted.

In accordance with Section 5.01.8 of the NC LiDAR Standard, FVA shall be assessed and reported per the NDEP Elevation Guidelines. For this project, the project design ensures that the LiDAR is suitable for a 1ft contour product, or a threshold of ≤ 9.25cm RMSEz (18. 2cm FVA at the 95 percent confidence level). It is our understanding that the data will be independently tested after delivery by a third party therefore ESP's vertical accuracy test will utilize the project control and shall provide the following statement regarding FVA:

> *"Compiled to meet ≤ 18.2cm Fundamental Vertical Accuracy at the 95 percent confidence level in open terrain using RMSEz * 1.9600".*

The internal, calculated value for FVA will also be provided.

Task 8c: LiDAR Classification QA/QC

Process Overview

The QA/QC workflow for Task 8c encompasses a series of automated and manual review processes designed to identify potential issues throughout the task, as early as possible. During production, technicians will utilize peer review and lead technician reviews to ensure that quality is maintained throughout the classification process. When the classification process is completed, the data will undergo what is commonly known in the industry as "macro" and "micro" QA/QC. These processes are described in further detail below.

Peer and Lead Technician Review

Some of the common issues encountered during the LiDAR classification phase include:

1) Blunders caused by automated classification routines;
2) Blunders caused by a misinterpretation by the technician during editing;
3) Lack of homogeneity across tiles and blocks due to different work methods, quality, or technicians.

ESP's strong production QA/QC process is designed to catch such problems during production to prevent errors from propagating into other products and final deliverables. During the peer review process, technicians working on editing the LiDAR tiles will check each other's work. This ensures that every tile will be reviewed by more than one individual and that teams of individuals are executing the editing in the same manner.

Lead technicians on the production floor will be responsible for ensuring that the tiles and blocks completed by the production teams are consistent in quality and appearance. They will also be responsible for ensuring that processes and procedures are being followed. Once thoroughly reviewed by the lead technician, LiDAR tiles will be submitted to the QA/QC technicians.

Macro QA/QC Checks

Macro checks are executed via automated methods and quick visual QCs, allowing the reviewers to quickly identify potential systemic or gross errors in the product. Gross or systemic errors can often be caught with a macro check, ensuring that the product is rejected internally prior to the micro checks occurring. The macro checks for Task 3 include the following items shown in Table.

Table 9: Macro QA/QC checks.

QA/QC Step	Comments	Corresponding Standard/Specification
1. Verify completeness	Files are readable, correctly named	Naming convention – NC LiDAR Standard, Sections 1.05 and 5.04.2
2. Verify projection	Checked against project system – NC SPCS NAD83 (2011), NAVD88, Geoid 12A	Request for Delivery Order, DO 59
3. Review overall classification	No classifications in unused bins, variable length records present, min/max x, y, z ranges appropriate	Internal, contractual, and Section 5.03.3 of the NC LiDAR Standard
4. Check coverage	Data clipped correctly to tiles, project area and buffer covered	Contractual
5. Check for voids	Do not exceed 4*Nominal Pulse Spacing (NPS) except where caused by water bodies, low reflectivity, or is filled in by another swath/lift	NC LiDAR Standard Section 5.01.4
6. Check format	Tiles are in correct, deliverable format	LAS 1.4 per Request for Delivery Order, DO 59
7. Check density	Nominal pulse spacing (NPS) is 0.7 meter or better	Contractual

Micro QA/QC Checks

The micro checks consist of a detailed review, tile by tile, of the LAS product to ensure that the product meets the State's expectations in terms of the accuracy and consistency of the point classification. Per Section 5.03.3 of the NC LiDAR Standard, the classification accuracy of the LiDAR data shall meet or exceed the following test:

- Within any 1km x 1km area, no more than 2% of non-withheld points will possess a demonstrably erroneous classification value (including Classes 0 and 1)

A thorough, manual review of the data tile by tile facilitates this check. QA/QC technicians use a variety of methods to conduct this review using a combination of commercial off-the-shelf software (COTS), ancillary data (such as aerial imagery and GIS layers), and proprietary software. During this review, the technicians are inspecting the LAS product for:

1) Overly-aggressive editing
2) Vegetation or other above-ground features classified as ground
3) Ground points in water bodies
4) Proper depiction of roads, drainage patterns, and terrain
5) Bridges and buildings classified correctly
6) Water classifications match other products such as the hydro-flattening breakline layer

Please note that the following information is provided for clarification for items related to this delivery order:

1) For this project, the building classification is designed to meet a 90-95% classification accuracy therefore QA/QC of this classification will be limited to the identification of gross errors in the building classification.
2) LAS tiles will not be finalized for delivery until the associated hydro-flattening lines have been used to classify water points in the LAS so that the two products match

Final Accuracy Assessment

After the LAS QA/QC is completed for a particular block, a final accuracy assessment, incorporating calculations for SVA and CVA, will be conducted in accordance with the specifications in Sections 6.02.6 through 6.02.9 of the NC LiDAR Standard and in accordance with NDEP reporting guidelines.

As mentioned earlier in the proposal, ESP understands that a third-party accuracy assessment will be commissioned by the State. Therefore, ESP will be testing the LiDAR internally against the project control and will only provide "Compiled to meet" statements for FVA, SVA, and CVA.

- FVA Statement: "Compiled to meet ≤ 18.13cm Fundamental Vertical Accuracy at the 95 percent confidence level in open terrain using RMSEz * 1.9600"
- CVA Statement: "Compiled to meet 26.9cm Consolidated Vertical Accuracy at 95th percentile in open terrain, (insert other land cover categories tested)."
- SVA Statement: "Compiled to meet 26.9cm Supplemental Vertical Accuracy at 95th percentile in (insert land cover category tested)."

The internal, calculated values for FVA, SVA, and CVA will also be provided.

Task 8d: Hydro-Flattening Breaklines QA/QC

Process Overview

For Task 8d the QA/QC workflow will consist of reviewing the hydro-flattening breaklines visually and by comparing the line work to ancillary data and the LiDAR surface. The visual QC will ensure that there are no issues with the original horizontal placement of the line work and that the minimum features have been collected in accordance with Section 7 of the NC LiDAR Standard.

Other quality control checks such as spot-checking monotonicity of flowing water features and the elevations of closed water bodies will be conducted to ensure that the software-assisted portion of the collection is performing as planned.

All hydro-flattening breaklines will be checked against the specifications outlined in Section 7 of the NC LiDAR Standard prior to being approved for use in the generation of the DEM product.

Task 8e: ESRI Terrain Dataset QA/QC

Process Overview

The QA/QC process for Task 8f will be used as each county-level terrain dataset is completed. The QA/QC will involve opening the geodatabase created for each county in ArcMap version 10.0 or later and visually inspecting the database for compliance with the requirements. The file will be visually inspected to verify that:

1) Multipoint features will be stored as the Surface Feature Type (SFType) “mass points” and are embedded into the Terrain.
2) Breaklines developed as part of the project are included within the Terrain and have the appropriate SFType assigned based on the type of input feature.
3) The Pyramid Type was set to the Z Tolerance setting and the Pyramid Properties and Levels were calculated using the Calculate Pyramid Properties dialog within the ESRI Terrain development tool.

Task 8g: LiDAR Intensity Image QA/QC

Process Overview

The QA/QC process for Task 8g involves the manual review of the files over the entire project area to ensure that there are no gaps caused by processing and to review the product for the desired appearance. File format and naming convention for this deliverable will also be verified as a final check prior to delivery.

Task 8h: LiDAR Quality Review Support

Process Overview

To facilitate the efficient review of the submitted LiDAR data and other associated files, ESP suggests that the NCFMP use the LP360 Advanced QCoherent Software. This software configuration will provide the NCFMP with exploitation and analysis abilities in an ArcGIS environment. ESP will include the purchase 1 Node-locked license and 2 years of maintenance as part of the Business Proposal.

Project Deliverables

The following table summarizes the anticipated deliverables for each task:

Task	Deliverables
Task 1: LiDAR Data Acquisition	• Project Boundary GIS File and Map (State 5K tiling scheme with 100 meter buffer) • Flight Line Layout GIS File and Map • Ground Control GIS File and Map • Adjacent Contractor Coordination Agreement • GPS Ground Control Survey Points (approximately 700)
Task 2: Classification of LiDAR Points	• ASPRS LAS 1.3 Record Type 3 Classified LiDAR point clouds (full tiles of the State's 5K tiling scheme; approximately 14,400 tiles) • Fundamental Vertical Accuracy (FVA) Control Report
Task 3: Development of DEMS in ESRI Grid Format	• 3D Hydro-Breakline Files • *All datasets will be on the same tile scheme as the Classified LiDAR LAS files*
Task 4: Terrain Datasets by County	• Individual countywide Terrain Datasets within a File Geodatabase
Task 5: Intensity Images	• Intensity Image Files (8-bit, GeoTiff, 10 feet raster cell size) • *All datasets will be on the same tile scheme as the Classified LiDAR LAS files*
Task 6: Metadata	• FGDC Compliant metadata for classified LAS point clouds • FGDC Compliant metadata for Hydro-Breaklines • FGDC Compliant metadata for ESRI Terrain Datasets • FGDC Compliant metadata for Intensity Images
Task 7: Preparation of Project Reports	• Weekly Status Reports (up to 52) • Collection Report (mission planning and flight logs) • Survey Report (survey and calibration) • Processing Report (product generation and methodology)
Task 8: Quality Assurance/Quality Control Plan	• QA/QC Report

Project Schedule

The following table summarizes the anticipated delivery schedule for each task:

Task	Completion/Submission Date
Task 1: LiDAR Data Acquisition	05/02/2014
Task 2: Classification of LiDAR Points	08/08/2014
Task 3: Development of DEMS in ESRI Grid Format	09/19/2014
Task 4: Terrain Datasets by County	10/3/2014
Task 5: Intensity Images	10/3/2014
Task 6: Metadata	**Submitted with appropriate deliverable package*
Task 7: Preparation of Project Reports	**Submitted with appropriate deliverable package*
Task 8: Quality Assurance/Quality Control Plan	11/07/2014

Optional Tasks – Value Added Products

As requested by the State as part of the RFDO, ESP is presenting a list of Optional Tasks that the State has the ability to activate at any time during the duration of or after the end of the initial LiDAR project.

Optional Task 1A: Stream Level Detail Hydro-Enforcement

As part of Task 1A ESP will perform Stream Level Detail Hydro-Enforcement, which will capture 3D enabled breaklines for all streams up to 1 square mile of drainage area. The following is a summary of the technical approach and scope of services for Task 1A.

Task 1A: Stream Level Detail Hydro-Enforcement

Process Overview

This process includes all streams visible in the DEM ≥ 1 mile in length and all water bodies ≥ 0.5 acres are compiled and hydro-enforced. In addition the stream level detail includes connectors at culvert crossings. These connectors will be included as a geodatabase feature class and will not be allowed to burn through the DEM. This type of feature class will enable subsequent placement of physical culvert attributes that are typically used in high detailed level modeling.

Optional Task 1B: Stream Level Detail Hydro-Enforcement (USGS/NRCS Area)

As part of Task 1B ESP will perform Stream Level Detail Hydro-Enforcement, which will capture 3D enabled breaklines for all streams up to 1 square mile of drainage area. The following is a summary of the technical approach and scope of services for Task 1B.

Task 1B: Stream Level Detail Hydro-Enforcement

Process Overview

This task assumes the same process will be followed as in Optional Task 1A, but the work will be performed on the USGS and NRCS data that was collected and processed for the Phase 1 area of North Carolina's LiDAR Refresh, commonly referred to as the Sandy LiDAR.

Optional Task 2A: High Detail Road Classifications

As part of Optional Task 2A ESP will compile High Detail Road Classifications within the LiDAR point cloud. The following is a summary of the technical approach and scope of services for Optional Task 2A.

Task 2A: High Detail Road Classification

Process Overview

In order to best capture the extent of the roadways within the project area ESP will use a two phase approach. Phase one will be completed via Remote Sensing using a Supervised Classification. ESP will utilize existing layers provided by the State as supplemental or seed processing. The layers to be provided will be any available spatial GIS files such as road centerlines, extent ribbons, and planimetrics. Each file used as a seed must have available metadata to determine the accuracy of the data, which will allow a more accurate allocation of value in the Supervised Classification. This Remote Sensing approach in many instances will be able capture approximately 80-90% of the LiDAR points that were collected along the roads. Phase Two of the High Detail Road Classification will supplement the Phase One results with a manual clean-up of the Supervised Classification. The results of the manual editing will yield a higher level of detail and ensure more of the actual LiDAR points that are within the roadway are captured and classified as Roads in the LiDAR classification scheme.

Optional Task 2B: High Detail Road Classifications (USGS/NRCS Area)

As part of Optional Task 2B ESP will compile High Detail Road Classifications within the LiDAR point cloud. The following is a summary of the technical approach and scope of services for Optional Task 2B.

Task 2B: High Detail Road Classification

Process Overview

This task assumes the same process will be followed as in Optional Task 2A, but the work will be performed on the USGS and NRCS data that was collected and processed for the Phase 1 area of North Carolina's LiDAR Refresh, commonly referred to as the Sandy LiDAR.

Optional Task 3A: Automated Road Classifications

As part of Optional Task 3A ESP will compile Automated Road Classifications within the LiDAR point cloud. The following is a summary of the technical approach and scope of services for Optional Task 3A.

Task 3A: Automated Road Classifications

Process Overview

In order to capture the extent of the roadways within the project area ESP will use a Remote Sensing approach using a Supervised Classification. ESP will utilize existing layers provided by the State as supplemental or seed processing. The layers to be provided will be any available spatial GIS files such as road centerlines, extent ribbons, and planimetrics. Each file used as a seed must have available metadata to determine the accuracy of the data, which will allow a more accurate allocation of value in the Supervised Classification. This Remote Sensing approach in many instances will be able capture approximately 80-90% of the LiDAR points that were collected along the roads. For the purposes of this task it is assumed that no manual clean-up of the Supervised Classification will be performed.

Optional Task 3B: Automated Road Classifications (USGS/NRCS Area)

As part of Optional Task 3B ESP will compile Automated Road Classifications within the LiDAR point cloud. The following is a summary of the technical approach and scope of services for Optional Task 3B.

Task 3B: Automated Road Classifications

Process Overview

This task assumes the same process will be followed as in Optional Task 3A, but the work will be performed on the USGS and NRCS data that was collected and processed for the Phase 1 area of North Carolina's LiDAR Refresh, commonly referred to as the Sandy LiDAR.

Optional Task 4A: Bridge Classification

As part of Optional Task 4A ESP will conduct a Bridge Classification within the LiDAR point cloud. The following is a summary of the technical approach and scope of services for Task 4A.

Task 4A: Bridge Classification

Process Overview

ESP will reference the North Carolina Department of Transportation (NCDOT) published Bridge Inventory shapefile to identify state-maintained bridges within the project area. Each bridge will located within the point cloud tile. Once located, the LiDAR Analyst will use their best judgment to determine what points to include in the bridge classification scheme. A sample dataset will be provided to the State before all bridges are classified to ensure that the extent of the classification will meet their business needs. Once the approach is approved, ESP will continue to classify the LiDAR points associated with each bridge located within the NCDOT Bridge Inventory.

Optional Task 4B: Bridge Classification (USGS/NRCS Area)

As part of Optional Task 4B ESP will conduct a Bridge Classification within the LiDAR point cloud. The following is a summary of the technical approach and scope of services for Task 4B.

Task 4B: Bridge Classification

Process Overview

This task assumes the same process will be followed as in Optional Task 4A, but the work will be performed on the USGS and NRCS data that was collected and processed for the Phase 1 area of North Carolina's LiDAR Refresh, commonly referred to as the Sandy LiDAR.

Optional Task 5A: Building Change Detection

As part of Task 5A ESP will perform a Building Change Detection analysis. The following is a summary of the technical approach and scope of services for Task 5A.

Task 5A: Building Change Detection

Process Overview

ESP will conduct a Building Footprint Extraction routine that will detect removed, added, or modified building footprints with the project area. This approach is much more cost effective than the traditional manual digitization. The first step in this process will be completed via Remote Sensing using a Supervised Classification. ESP will utilize the most current building footprints for each county as provided by the State for supplemental or seed processing. These feature classes, along with the classified LiDAR and Intensity Values will aid in forming the algorithm to extract areas of change. Once these areas of change have been identified ESP will update the particular buildings associated with these areas using polygons that are generated from the LiDAR and resulting Supervised Classifications. ESP will maintain the appropriate Building IDs and create new IDs when necessary in order to facilitate the easy implementation of the spatial updates to a building footprint layer that may be at various stages of completeness through the NCFMP Risk Assessment Process.

Optional Task 5B: Building Change Detection (USGS/NRCS Area)

As part of Task 5B ESP will perform a Building Change Detection analysis. The following is a summary of the technical approach and scope of services for Task 5B.

Task 5B: Building Change Detection

Process Overview

This task assumes the same process will be followed as in Optional Task 5A, but the work will be performed on the USGS and NRCS data that was collected and processed for the Phase 1 area of North Carolina's LiDAR Refresh, commonly referred to as the Sandy LiDAR.

Optional Task 6A: Impervious Layer Development

As part of Task 6A ESP will create a GIS-based Impervious Layer using an Automated Impervious Mapping technique. The following is a summary of the technical approach and scope of services for Task 6A.

Task 6A: Impervious Layer Development

Process Overview

Impervious Layer development can often be a tedious process leading to questionable results due to the varying data sources and their subsequent accuracies. Each of these varying datasets must be compiled into a singular dataset, which leads to numerous topologic issues and inconsistencies. ESP's approach to conducting automated impervious mapping utilizes the Ecognition platform, and supplemental seed files, such as building footprints, roads, existing planimetrics, and the classified LiDAR points and associated intensity values. Each of these files will be assigned a weighted value in the Supervised Classification algorithm, and then multiple iterations of this algorithm are processed using a variable weight scenario. Once the first iterations are complete the results are reviewed for validity. Each feature type will be reviewed and correspondence will be taken on the particular weighted combination that yielded the most favorable results. Then a second set of iterations with an improved weighting methodology will be conducted and again the results will be reviewed and documented. This iteration cycle will continue until each feature has been optimized with its' particular algorithm weight and then the final processing will yield a singular GIS layer containing attributes for feature type and calculated area.

Optional Task 6B: Impervious Layer Development (USGS/NRCS Area)

As part of Task 6B ESP will create a GIS-based Impervious Layer using an Automated Impervious Mapping technique. The following is a summary of the technical approach and scope of services for Task 6B.

Task 6B: Impervious Layer Development

Process Overview

This task assumes the same process will be followed as in Optional Task 6A, but the work will be performed on the USGS and NRCS data that was collected and processed for the Phase 1 area of North Carolina's LiDAR Refresh, commonly referred to as the Sandy LiDAR.

Optional Task 7A: USGS/NRCS LiDAR Classification Upgrade

As part of Task 7A ESP will conduct an ASPRS Classification upgrade to the classified USGS/NRCS LiDAR datasets. The following is a summary of the technical approach and scope of services for Task 7A.

Task 7A: USGS/NRCS LiDAR Classification Upgrade

Process Overview

Based on the requirements set forth in the USGS Specifications for the Sandy LiDAR collection, it is understood that those LiDAR point clouds will be classified as shown in Table 10.

Table 10: USGS LiDAR Classification Requirements.

Class	Description
1	Processed Unclassified
2	Ground
7	Noise (High/Low)
9	Water
10	Ignored Ground

The purpose of this task is to upgrade the classification of the LiDAR Point cloud to match the ESP project area as shown in Table 11.

Table 11: ESP Proposed Classification Scheme.

Class	Description
1	Processed Unclassified
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Buildings (Automated)
7	Noise (High/Low)
9	Water (Hydro Cleaned Areas)
12	Flight Line Overlap

ESP will review the classified LiDAR data provided by the USGS and NRCS and re-process the data using a new set of algorithms and macros to compile a more homogenous dataset for the State. It will be assumed that all points classified in the USGS and NRCS datasets as Class 2 Ground and Class 9 Water will remain unchanged.

Optional Task 8A: Gravity Grant Coordination

As part of Task 8A ESP will conduct an ASPRS Classification upgrade to the classified USGS/NRCS LiDAR datasets. The following is a summary of the technical approach and scope of services for Task 8A.

Task 8A: Gravity Grant Coordination

Process Overview

ESP will coordinate with the North Carolina Office of Geospatial and Technology Management (NC GTM), the North Carolina Geodetic Survey (NCGS), and selected North Carolina University representatives to conduct scientific gravity research.

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Appendixes

Appendix A: Requested Technical Specification Exemptions

In accordance with the North Carolina Technical Specifications for LiDAR Base Mapping, dated 2/15/2012, and this Delivery Order, ESP is requesting Specification Exemption for the items listed below.

Section 3.01.3 – *North Carolina Technical Specifications for LiDAR Base Mapping*

- **Flightline Overlap**
  - **Specification**
    - 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%.
  - **ESP Recommendation**
    - Reduce the Flightline Overlap specification to 20%.
    - Please refer to *Task 1a – Flightline Overlap*, for supporting details.

Section 3.01.4 – *North Carolina Technical Specifications for LiDAR Base Mapping*

- **Buffering**
  - **Specification**
    - Project boundary shall be buffered by a minimum of 2,000 feet. Buffer areas may be adjusted by Contracting Officer.
  - **ESP Recommendation**
    - Update the Buffering specification to extend 100 Meters beyond all 5,000 feet by 5,000 feet tiles that intersect the political boundaries of the counties within the project area.
    - Please refer to *Task 1a – Project Boundary and Buffer*, for supporting details.

Section 4.02 – *North Carolina Technical Specifications for LiDAR Base Mapping*

- **North Carolina *In Situ* Validation Range Requirements**
  - **Specification**
    - The state of North Carolina has developed an *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.
  - **ESP Recommendation**
    - Update the established In Situ Validation Range to a new location as shown in Figure 4 of this Technical Proposal.
    - Please refer to *Task 1a – In Situ Validation Range*, for supporting details.

Section 4.03 – *North Carolina Technical Specifications for LiDAR Base Mapping*

- **Daily Calibration Survey**
  - **Specification**
    - 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 flightlines 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.
  - **ESP Recommendation**
    - Waive the Daily Calibration Survey requirement and adopt ESP's proposed Calibration Methodology.
    - Please refer to *Task 1d – Calibration* for supporting details.

Section 9.13 – *North Carolina Technical Specifications for LiDAR Base Mapping*

- **Deliverables; Bare Earth Surface (Raster DEM)**
  - **Specification**
    - A Bare Earth Surface DEM shall be delivered and is a standard requirement for LiDAR Projects.
  - **ESP Recommendation**
    - Waive the requirement for delivery of Bare Earth Surface DEMs, based upon the State's request.
    - Please refer to *Task 3a – Hydro-Breakline Generation* for supporting details.
    - It is noted that the hydro-flattened DEMs in the *North Carolina Technical Specifications for LiDAR Base Mapping, Section 3.01.2.6 – Principal Contract Deliverables; DEM (Hydro-Flattened)* are required as a deliverable, so this exemption also applies to that section of the specifications.

Appendix B: Project Equipment List

The following equipment is available and is planned for use with this delivery order from the ESP Team.

Aircraft				
Plane	**Tail #**	**Owner**		
Cessna 335	N27EH	Surdex		
Cessna 402C	N4661N	Merrick		
Patenavia P68-C	775MW	Atlantic		
LiDAR Systems				
LiDAR Systems	**Serial Number**	**IMU**	**Flight Management**	**Owner**
Leica ALS70-HP	7123	IPAS GNSS-IMU	Leica FCMS	Atlantic
Leica ALS70-HP	7198	IPAS GNSS-IMU	Leica FCMS	Surdex
Optech Pegasus HA500	13SEN298	NG LN-200	Optech FMS	Merrick
GPS Equipment				
GPS Equipment	**Make**	**Model**	**Serial Number**	
GPS Receiver	Trimble	R10	5338443627	
GPS Receiver	Trimble	R8GNSS Model 3	4622117106	
GPS Receiver	Trimble	R10	5339444110	
GPS Receiver	Trimble	R8GNSS Model 3	5005414882	
GPS Receiver	Trimble	R10	5339444155	
GPS Receiver	Trimble	R8GNSS Model 3	5005414876	
GPS Receiver	Trimble	R10	5343446168	
GPS Receiver	Trimble	R8GNSS Model 3	5005414796	
GPS Receiver	Trimble	R8GNSS Model 3	5005414789	
GPS Receiver	Trimble	R8GNSS Model 2	4620114542	
GPS Receiver	Trimble	R8 Model 1	4515147819	
Data Collector	Trimble	TSC3 w/2.4 GHz Radio	RS1MC33522	
Data Collector	Trimble	TSC3 w/2.4 GHz Radio	RS1MC33540	
Data Collector	Trimble	TSC3 w/2.4 GHz Radio	RS1MC32968	
Data Collector	Trimble	TSC3 w/2.4 GHz Radio	RS23C42061	
Data Collector	Trimble	TSC3	RSOUC15944	
Data Collector	Trimble	TSC3	RSOUC15972	
Data Collector	Trimble	TSC3 w/2.4 GHz Radio	RS20C41202	
Data Collector	Trimble	TSC3	RS0UC16314	
Ground Control Survey Vehicles				
Make	**Model**	**Year**	**VIN**	**TAG**
FORD	F150	2006	1FTRX14W66NA45091	VTC6581
FORD	F250	2012	1FT7X2BT6CEB12936	DY1206
FORD	F150	2012	1FTFX1EF9CFB26187	BLL9263
FORD	F150	2012	1FTFX1EF2CFC68154	ALF4073
FORD	F150	2013	1FTFX1EF3DFC53518	EK3309

Processing Software			
Platform	**Quantity**	**Platform**	**Quantity**
Applanix Pospac	9	Merrick MARS	Unlimited
Bently Microstation V8i	9	Optech Dash Map PP	3
eCognition Developer	2	Optech Mapping Suite	3
eCognition Server	3	QCoherent LP360	6
ESP Analyst	Unlimited	Terrasolid Terramatch	4
ESRI ArcGIS 10.x	3 Enterprise Editions	Terrasolid TerraScan	9
Leica ALSPP	Unlimited		