Issue 5: Quality Control of LIDAR Elevation Data in North Carolina

Background:

The requirements for digital elevation data for flood insurance studies should be determined early in the process. Typically, for hydraulic modeling, elevation data equivalent to 4' contours (RMSE = 37 cm) are appropriate for rolling to hilly terrain, and elevation data equivalent to 2' contours (RMSE = 18.5 cm) are appropriate for flat terrain. North Carolina specified a RMSE of 20 cm for coastal counties and RMSE of 25 cm for inland counties.

Recommendations:

The NC mapping effort should follow the procedures, discussed below, that are currently being used to ensure quality control of the digital elevation data being obtained.

Phase 1: Independent QC Checkpoints

1.1 Land Cover Categories: Working with the NC Center for Geographic Information and Analysis (CGIA), the NC Geodetic Survey (NCGS) will categorize all land into one of five major land cover categories representative of the floodplains: a) bare-earth and low grass (e.g., sand, rock, plowed fields, lawns, golf courses); b) high grass, weeds, and crops (e.g., hay, corn, wheat, tobacco); c) brush lands and low trees; d) fully forested; and e) urban areas (vicinity of manmade structures, preferably high density).

1.2 Checkpoint Selection: For each county, NCGS will direct independent survey contractors to select 30 or more checkpoints, in each of the five land cover categories (10 of these will be held in reserve for subsequent QC). Each checkpoint should be on terrain that is flat or uniformly sloping within 5 meters in all directions (i.e., no breaklines within 5 meters of the checkpoint). For fully forested areas, the NCGS will select 40 checkpoints to allow for some checkpoints to be discarded should LIDAR vendors indicate that the vegetation is too dense for LIDAR penetration. CGIA will provide county maps of land-cover categories, and the survey contractors will be provided with large-area polygons dispersed throughout each county within which the surveyors will select the checkpoints. Where possible, checkpoints should be interspersed throughout a county area so that checkpoints will cover different flightlines. For example, if LIDAR flightlines are generally north-south, it is ideal for surveyors to survey in the vicinity of east-west roads in order to disperse checkpoints to cover different flightlines.

1.3 Checkpoint Surveys: NCGS will contract for independent surveys of all checkpoints to 5-cm Local Network accuracy according to NOAA Technical Memorandum NOS NGS-58, "Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)," Version 4.3, November 1997 (referred to as NGS-58). Monuments selected for differential GPS base stations should have the best available Vertical Order, Stability C or better, with preference given to NC HARN monuments. If selected monuments are farther than 20 km from the test areas to be surveyed, Secondary Base Stations will be established so that final surveys of checkpoints will satisfy NGS-58 requirements for Local Network accuracy of 5-cm at the 95% confidence level. Alternatively, GPS RTK may be used provided: (1) the DGPS base station is an existing NGS 3-D mark or a new NGS-58 mark, (2) RTK can only be used in open areas, and each RTK point must be occupied twice with at least 2 hours difference in time between observations, and (3) the difference between observations must not exceed 5 cm. Third-order conventional surveys may be used to extend control from open areas (surveyed by GPS) to forested areas where GPS signals are blocked.

1.4 Documentation: The survey company will mark each checkpoint with a 60d nail or larger. The station ID number will be written on an adjacent above-ground stake within 1 foot of the referenced stake. "To reach" descriptions and photographs will be used to document the location, the land cover surrounding each stake, and the uniform slope of the terrain surrounding each stake.

1.5 Orthometric Heights: Geoid99 will be used to convert GPS ellipsoid heights into orthometric heights for each checkpoint, using NAVD 88, the specified vertical datum.

1.6 3-D Coordinate Files: The surveyor will provide NCGS with ASCII 3-D point files (x/y/z values) by State Plane coordinates (meters) to 3 decimal places.

1.7 Security: NCGS will ensure that these 3-D coordinate files are secured and not made available outside of NCGS.

Phase 2: LIDAR Accuracy Assessment

2.1 LIDAR Acquisition Plans: The LIDAR vendor will provide NCGS with acquisition planning information, including, but not limited to, flightline directions, types of sensors, pulses per second, flying altitude above mean terrain, swath width, average point spacing, maximum positional dilution of precision (PDOP), maximum airborne GPS baselines, and sidelap percentage.

2.2 LIDAR Acquisition Data: Upon request, the LIDAR vendor will provide NCGS with actual data for each sensor on each day, to include daily calibration results, flying altitude, average point spacing, maximum PDOP, maximum GPS baselines, etc., plus maps showing actual flightlines and swaths, by dates acquired and sensors (when multiple LIDAR systems are used).

2.3 Bare Earth Data: The LIDAR vendor will post-process the LIDAR data to generate bare earth 3-D ASCII files or Triangulated Irregular Network (TIN) files.

2.4 Interpolated z-values: When notified that the ASCII/TIN data are complete, NCGS will provide 2-D (x/y coordinates without z-values) of 20 checkpoints per land cover category (holding additional checkpoints in reserve) to the LIDAR vendor. The vendor immediately (within a few minutes) computes the interpolated LIDAR z-values for the x/y coordinates of the checkpoints and provides 3-D (x/y/z) files to NCGS. Fewer than 20 checkpoints may be allowed in some land cover categories, if difficulty is encountered in finding certain vegetation groups.

2.5 100% RMSE Calculations: NCGS will compute the vertical RMSE for 100% of the checkpoints evaluated.

2.6 95% RMSE Calculations: NCGS will discard the worst 5% of the points (allowing 5% of the points to have unclean vegetation removal) and will recompute the RMSE using the best 95% of the original checkpoints. NCGS will then provide both sets of RMSE calculations to the Map Coordination Contractor (MCC).

2.7 RMSE by Land Cover Category: The MCC will compute separate RMSEs for the five different land cover categories.

2.8 Comparison with Accuracy Criteria: If the 95% RMSE calculation from Task 2.6 passes the accuracy criteria (20-cm or 25-cm), the MCC will prepare a LIDAR Accuracy Assessment Report indicating this fact. The LIDAR Accuracy Assessment Report will report the statistics, compared with the relevant accuracy standard, and include graphs of RMSEs by land-cover categories. If the RMSE does not pass the accuracy criteria, the process moves to Phase 3 discussed below. The MCC will provide this report to NCGS, and NCGS will provide the report, with additional comments as appropriate, to the mapping contractor.

Phase 3: Error Assessments

3.1 Assessments by Land Cover: The causes for the data to not pass the accuracy criteria (20-cm or 25-cm) differ according to land-cover category. Typically, data in category a should pass the accuracy criteria, unless there is a systematic problem; however, the daily calibration results should confirm that the system performed well at the calibration test site (on that same day with the same sensor), and the calibration site should be on bare terrain or short grass only. If data in land-cover categories c or d alone do not pass the accuracy criteria, the most probable causes are shortcomings in the vegetation-removal procedures. If data in category e does not pass, the most probable cause is a systematic problem with handling buildings.

3.2 Assessments by Error Locations: The MCC will evaluate the location of significant errors to see if they are consistent throughout the area and to determine where these errors are located within the flightline (e.g., near the beginning or end of swaths).

3.3 Assessments by Dates/Sensors: The MCC will evaluate the datasets to see if errors are distinguishable by dates or by individual sensors.

3.4 Accuracy Assessment Report: If the above assessments do not yield the probable source of systematic errors, the MCC will prepare an Accuracy Assessment Report indicating that the LIDAR data did not pass the accuracy criteria. This report will include the same type of information in task 2.8 above, but with a printout of z-value errors, sorted by elevations, without x/y coordinates. The report may identify polygons within which major errors are clustered, to assist in trouble-shooting. The report may recommend that NCGS spot check the elevations on several of the independent checkpoints that yielded the poorest results when compared with the interpolated LIDAR elevations, or the report may recommend that the LIDAR vendor assess the quality of individual components (airborne GPS, inertial measuring unit (IMU), and laser ranges) as well as the integrated system, with technical assistance from the MCC, if requested.

3.5 Airborne GPS Verification: The LIDAR vendor will examine GPS flight trajectories, verify the PDOP and vertical dilution of precision, verify GPS satellite residuals, verify the satellite phase RMS, compare forward and reverse flight trajectories' combined separation, verify weighting adjustments when two or more differential base stations are used, verify the base station distance separation, verify position standard deviations, check satellite health, check geo-magnetic observations, verify that the correct vertical datum was used, and verify the correct application of the Geoid99 calculation of orthometric heights.

3.6 IMU Verification: The LIDAR vendor will review the Kalman filter, the measurement residual ratio (MRR), and the consecutive measurement rejections settings; confirm that the IMU was in "fine align" mode for the whole of the data set; check accelerometer drift and scale factor and gyro drift and scale factor to ensure that they are within specifications; compare GPS trajectory with re-computed IMU trajectory and investigate large discrepancies; and review IMU to lever arm parameter measurements and ensure that they are entered correctly in the proper reference system.

3.7 Laser Range Verification: The LIDAR vendor will review raw laser ranges; identify areas of high dropouts (no returns) and correlate them to justifiable features; review scanner mirror angles (galvanometers or micro-controller—LSR reports; examine intensity images, if collected; and review system-generated error log sheets.

3.8 Total System Verification: The LIDAR vendor will review daily calibration flights and compare to system flight parameters; use CAD software to analyze flight lines and verify pitch, roll, and heading errors; check overlap for roll and scaling errors; check ground features for pitch (e.g., buildings, bridges); if water bodies exist, check scaling errors; compare cross flight data for attitude; review parameters if data were "corrected" or adjusted for pitch, roll, and heading errors; and verify vegetation removal procedure.

3.9 Systematic Error Corrections: If systematic errors are found, the data will be reprocessed by the LIDAR vendor, with clear written explanations provided to NCGS for review by the MCC. If no systematic errors are found, the process moves to Phase 4 discussed below.

3.10 Recalculation of RMSE: Using additional QC checkpoints held in reserve, the LIDAR vendor will interpolate the LIDAR dataset for the new checkpoint 2-D (x/y) coordinate values and provide 3-D (x/y/z) files for recomputation of 100% and 95% RMSEs by NCGS. The results will be provided to the MCC. NCGS may task the QC contractor to collect additional points from those points held in reserve.

3.11 LIDAR Accuracy Assessment Report: If the 95% RMSE calculation from task 3.10 passes the accuracy criteria (20-cm or 25-cm), the MCC will prepare a LIDAR Accuracy Assessment Report indicating this fact. If the RMSE does not pass the accuracy criteria, a provisional Accuracy Assessment Report will document the new statistics and recommend alternatives (when pre-approved by NCGS) listed in Phase 4. The MCC will provide this report to NCGS, and NCGS will provide the report, with additional comments as appropriate, to the mapping contractor.

Phase 4: Final Resolution of Problems

4.1 Provisional LIDAR Accuracy Assessment Report: As coordinated by the MCC with NCGS, the provisional Accuracy Assessment Report will document the accuracy assessments and recommend resolution to problems identified.

4.2 LIDAR Vendor Checkpoints: The LIDAR vendor will provide NCGS with checkpoints used to control the LIDAR adjustments, so that NCGS can determine the proximity of the LIDAR vendor checkpoints to the NCGS checkpoints or perform independent surveys of the vendor's checkpoints.

LIDAR Vendor Control Points: The LIDAR vendor will provide NCGS with control points and/or Least Squares Adjustments used to define the control points for the LIDAR processing. This will allow the NCGS to perform an independent analytical assessment of the vendor's control points to determine if there are any fundamental flaws or discrepancies in the control used for the project area. If the control points are inaccurate, the LIDAR vendor will need to resolve the control point(s) issue and reprocess the LIDAR data to fit the new control values. If the control points used are accurate, then 4.3 shall be implemented.

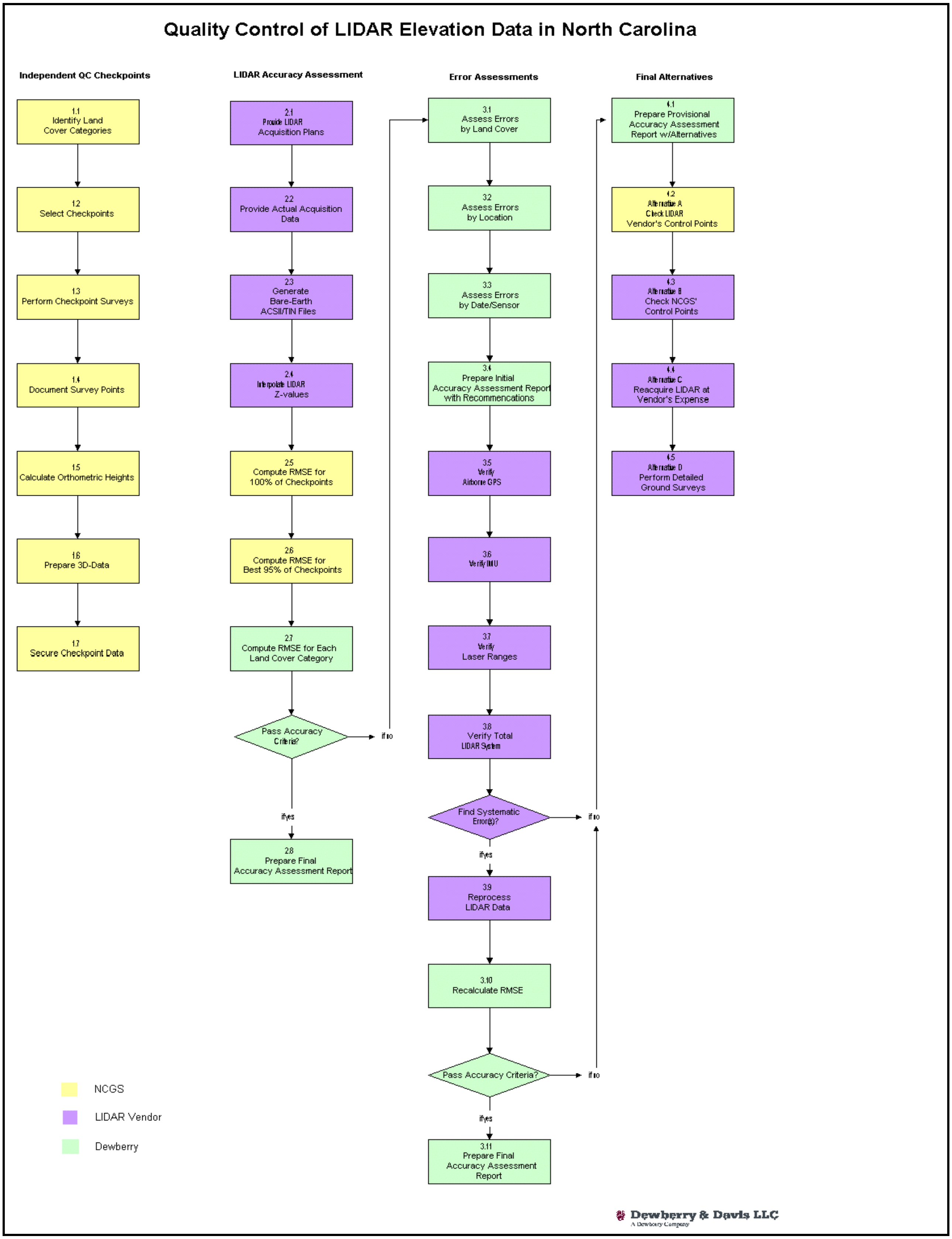
4.3 Potential Resurveys of Checkpoints: The LIDAR vendor will be provided with all of NCGS' 3-dimensional coordinates and will be afforded the opportunity to independently survey the checkpoints used for the RMSE calculations.

LIDAR Vendor Checkpoints: The LIDAR vendor will provide NCGS with the checkpoints and associated report documentation supporting LIDAR verification, which can include Least Squares Adjustment and/or GPS software auxiliary reports. NCGS will perform an independent analytical assessment of the checkpoints. If the checkpoints used by the vendor are inaccurate or non-conclusive, the vendor shall comply with NCGS' results and establish procedures to correct the LIDAR data through re-processing and/or reacquisition of data or proceed to 4.4.

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

Potential Resurveys of Checkpoints: The LIDAR vendor will be provided with all of NCGS' 3-dimensional coordinates with supporting documentation and will be afforded the opportunity to independently survey and analyze the checkpoints used for the RMSE calculations at the vendor's expense. If discrepancies are found with the NCGS coordinates, NCGS will rectify the problem and reassess the LIDAR data. If no discrepancies are found, the vendor shall comply with NCGS results and establish procedures to correct the LIDAR data through re-processing and/or reacquisition of the data.

4.5 Detailed Ground Surveys: The LIDAR firm may be offered the opportunity to perform extensive ground surveys of cross sections to satisfy the data needs for hydraulic modeling.


Quality Control of LIDAR Elevation Data in North Carolina
Independent QC Checkpoints
LIDAR Accuracy Assessment
Error Assessments
Final Alternatives
1.1 Identify Land Cover Categories
1.2 Select Checkpoints
1.3 Perform Checkpoint Surveys
1.4 Document Survey Points
1.5 Calculate Orthometric Heights
1.6 Prepare 3D-Data
1.7 Secure Checkpoint Data
2.1 Provide LIDAR Acquisition Plans
2.2 Provide Actual Acquisition Data
2.3 Generate Bare-Earth ACSII/TIN Files
2.4 Interpolate LIDAR Z-values
2.5 Compute RMSE for 100% of Checkpoints
2.6 Compute RMSE for Best 95% of Checkpoints
2.7 Compute RMSE for Each Land Cover Category
Pass Accuracy Criteria?
if no
if yes
2.8 Prepare Final Accuracy Assessment Report
3.1 Assess Errors by Land Cover
3.2 Assess Errors by Location
3.3 Assess Errors by Date/Sensor
3.4 Prepare Initial Accuracy Assessment Report with Recommencations
3.5 Verify Airborne GPS
3.6 Verify IMU
3.7 Verify Laser Ranges
3.8 Verify Total LIDAR System
Find Systematic Error(s)?
if no
if yes
3.9 Reprocess LIDAR Data
3.10 Recalculate RMSE
Pass Accuracy Criteria?
if no
if yes
3.11 Prepare Final Accuracy Assessment Report
4.1 Prepare Provisional Accuracy Assessment Report w/Alternatives
4.2 Alternative A Check LIDAR Vendor's Control Points
4.3 Alternative B Check NCGS' Control Points
4.4 Alternative C Reacquire LIDAR at Vendor's Expense
4.5 Alternative D Perform Detailed Ground Surveys
NCGS
LIDAR Vendor
Dewberry
Dewberry & Davis LLC
A Dewberry Company

Discussion Summary:

Date Discussed:	July 3, 2001
Discussion Attendees:	Floodplain mapping core
Summary of Discussion:	Recommendations were adopted.

Final Guidelines:

Guidelines follow the procedures discussed in the “Recommendations” section of this issue.

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