LiDAR Workflow and Quality Control Plan & Report
St. Croix County, WI 2014

LiDAR Quality Control/Quality Assurance Procedures

Quality Assurance/Quality Control (QA/QC) is an integral part of all aspects of any project. QA/QC begins at the proposal and mission planning stages, and continues through the field operations and data processing/data delivery in the office. It also includes assuring successful delivery of required materials and follow-up with the client to assure satisfaction.

Cooperative quality control is the coordinated effort that takes place when the project's technical project managers works in concert with County staff to quality-check and organize project deliverables, develop related documentation, and execute the final partnership deliveries.

Quality checks of the data should use a redundant approach with St. Croix County and the Ayres Associates/Quantum Spatial team examining the data in parallel. It is critical that the parallel QC processes be coordinated so issues can be addressed efficiently as they arise. Communication is crucial for correctly addressing issues so impacts to the overall delivery time frame are minimized.

Although every project performed by Ayres Associates and Quantum Spatial has different specifications that necessitate different technical solutions, the team employs a proven project approach which has been refined over years of experience with each other. The sequential phases of this approach are:

- Detailed Project Planning
- LiDAR Acquisition
- Data Processing and Mapping
- Final QA/QC, documentation, and delivery

In addition, throughout the complete project lifecycle, two key activities are executed: Project Management (including client communications and feedback, subcontractor coordination, as well as schedule and budget monitoring) and Quality Assurance & Quality Control (QA/QC) to ensure that all final specifications will be met. Using this integrated approach, the Ayres Associates/Quantum Spatial team will assure that all project specifications are met, and that all deliverables are received by St. Croix County on time.

QA/QC Management

Ayres Associates' LiDAR supervisor, Matt Vinopal, will be responsible for the LiDAR QA/QC. In that capacity, he will work with Mr. Contrucci to fulfill our team's commitment to providing quality products and services. In his role, our supervisor has a number of specific technical workflows. The first step in the LiDAR QA/QC process is to review mission logs and examine mission parameters. The second step is an automated/manual edit of the raw data. This process will ensure the removal of extraneous points and artifacts. Additionally, it will determine that all desired features have been retained within the data set. Filtered and edited data are subjected to rigorous QA/QC according to the Ayres Associates Quality Control Plan. A series of quantitative and visual procedures is employed to validate the accuracy and consistency of the filtered and edited data.

Initial QC

For this phase of the project, the following specifications are checked against the actual data collection and quality results:

- Nominal Pulse Spacing (NPS), or point density and points per square meter (PPSM) for first return data.
- Spatial distribution of points is uniform and free from clustering.
- Flight planning and data acquired encompass a 500-foot buffer surrounding project boundary.
- Multiple returns from any given pulse are stored in order and point families remain intact.
- Each return includes: easting, northing, elevation, intensity, order of return (i.e. first-return, second-return), classification, GPS week, GPS second. Easting, northing, and elevation must be recorded to the

nearest 0.01 meter and GPS second reported to the nearest microsecond (or better). May include additional attributes but no duplicate entries.

- Minimum 50% overlap on adjoining swaths.
- No voids between swaths.
- Must be cloud, smoke, dust, and fog-free between the aircraft and ground.
- At least two (2) GPS reference stations in operation during all missions, sampling positions at 1 Hz or higher frequently. Differential GPS baseline lengths shall not exceed 30 km. Differential GPS unit in aircraft shall sample position at 2 Hz or more frequently.

After our technicians establish the smoothed best estimate of trajectory (SBET), they apply the solution to the dataset in order to adjust each point based on aircraft position and orientation during LiDAR acquisition. To correct angular misalignments (roll, pitch, and heading errors), a manual bore sight calibration is employed before each day's mission to fine-tune the bore sight angles. It is at this point, as part of our LiDAR QA/QC procedure, that a review of the mission logs and mission parameters are performed.

Classified LAS Point Clouds

LiDAR data processing for the point cloud deliverable consists of classifying the LiDAR using a combination of automated classification and manual edit/reclassification processes. On most projects the automated classification routines will correctly classify 90-95% of the LiDAR points. The remaining 5-10% must undergo manual edit and reclassification. The manual editing of lidar points applies to the bare earth ground class only.

Because the classified points serve as the foundation for the Terrain, DEM and breakline products, it is necessary for the QA/QC supervisor to review the completed point cloud deliverables prior to the production of any additional products.

The following workflow steps are followed for **automated** LiDAR classification:

1. Lead technicians review the group of LiDAR tiles to determine which automated classification routines will achieve the best results. Factors such as vegetation density, cultural features, and terrain can affect the accuracy of the automated classification. The lead technicians have the ability to edit or tailor specific routines in order to accommodate the factors mentioned above, and achieve the best results and address errors.
2. Distributive processing is used to maximize the available hardware resources and speed up the automated processing as this is a resource-intensive process.
3. Once the results of the automated classification have been reviewed and passed consistent checks, the supervisor then approves the data tiles for manual classification.

The following workflow steps are followed for **manual edits** of the bare earth LiDAR classification:

1. LiDAR technicians review each tile for errors made by the automated routines and correctly address errors any points that are in the wrong classification. By methodically panning through each tile, the technicians view the LiDAR points in profile, with a TIN surface, and as a point cloud.
2. Any ancillary data available, such as Google Earth, is used to identify any features that may not be identifiable as points so that the technician can make the determination to which classification the feature belongs.

The QA/QC processes for the LiDAR processing phase consist of:

1. The lead technician reviews all automated classification results and adjust the macros as necessary to achieve the optimal efficiency. This is an iterative process, and the technician may need to make

several adjustments to the macros, depending upon the complexity of the features in the area being processed.

2. During the manual editing process, the LiDAR technicians use a system of QA, whereby they check each other's edits. This results in several benefits to the process:
3. There is a greater chance of catching minor blunders
4. It increases communication between technicians on technique and appearance
5. Solutions to problems are communicated efficiently
6. To ensure consistency across the project area, the supervisor reviews the data once the manual editing is complete.

For this phase of a project, the following specifications are checked against:

- Point cloud – all points must be classified according to the ASPRS classification standard for LAS. The all-return point cloud must be delivered in fully-compliant LAS version 1.2.
- LAS files will use the Spatial Reference Framework according to project specification and all files shall be projected and defined.

- General Point classifications:
    - Class 1. Processed, unclassified
    - Class 2. Bare-earth Ground
    - Class 5. High Vegetation
    - Class 6. Buildings
    - Class 7. Low Points (Noise)
    - Class 8. Reserved (Model Keypoints)
    - Class 9. Water
    - Class 10. Ignored ground (Breakline proximity)
    - Class 11. Withheld Points

- Outliers, noise, blunders, duplicates, geometrically unreliable points near the extreme edge of the swath, and other points deemed unusable are to be identified using the "Withheld" flag. This applies primarily to points which are identified during pre-processing or through automated post-processing routines. Subsequently identified noise points may be assigned to the standard Noise Class (Class7), regardless of whether the noise is lower or higher relative to the ground.
- Classification accuracy - within any 1 km x 1 km area, no more than 2% of non-withheld points in Class 2 (bare earth ground) will possess a demonstrably erroneous classification value. This includes Unclassified points (Class 1) that should be correctly included in a different class as required by this specification.
- Point classification shall be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, lifts, or other non-natural divisions will be cause for rejection.
- Once the data is imported into GeoCue and has undergone and passed the QC process, the strip data will be tiled to the 5000' x 5000' tiling scheme.

Breaklines

Once the classified point clouds have been reviewed and approved, the LiDAR can be used to generate the hydro-flattening breaklines. Once the breaklines are developed, they will also be used to hydro-enforce ESRI Terrains and Digital Elevation Model (DEM) products.

The following process steps are used to generate hydro-flattening breaklines:

1. The technician visualizes the LiDAR point cloud by intensity.

2. The technician then creates the hydro-breaklines using Terrasolid software, as well as ancillary sources (such as Google Earth) as a reference in areas where the features appear ambiguous.
3. Once the breaklines are completed, they are separated into layers containing polygonal breaklines and line features.
4. To further differentiate the type of water, the polygonal breaklines are then separated or classified as ponded water or flowing water.
5. Flowing water: Using downhill conflation rules, stream and river centerlines are digitized to enforce the hydrological representation of water flow. Once this is done, polygons are digitized to represent the stream or river banks. The elevation from the steam centerlines are then applied to the polygons so that each side of the bank has the same elevation.
6. Ponded water: is digitized using Terrasolid's conflation rule. Terrasolid determines the average elevation of the water represented by the polygon, conflates the breakline, and then classifies the LiDAR points inside of the polygon to water.
7. Breaklines representing ponds and rivers will be smooth and continuous, and monotonic, and represent the water surface without any stair steps except for dams and rapids.
8. The breaklines are then converted to the product deliverable format

The product undergoes QC by the supervisor and is reviewed for any omissions or blunders.

For this phase of the project, the following Statement of Work specifications are checked against:

- All breaklines developed for use in hydro-flattening shall be delivered as a non-tiled Esri feature class for the project area and/or polyline shapefile or geodatabase format. Water bodies (ponds, lakes, and reservoirs), wide streams and rivers ("double-line"), and other non-tidal water bodies are to be hydro-flattened within the DEM, resulting in a flat and level bank-to-bank gradient. The entire water surface edge must be at or below the immediately surrounding terrain.
- Breakline feature class will use the Spatial Reference Framework according to project specifications and shall be projected and defined.
- Hydro-flattening shall be applied to all streams that are nominally wider than 20 feet, and to all non-tidal boundary waters bordering the project area regardless of size.
- Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are nominally larger than 2 acres in area (equivalent to a round pond ~350' in diameter).
- Stream channels should break at road crossings (culvert locations). These road fills should not be removed from the DEM. However, streams and rivers should NOT break at elevated bridges. Bridges should be removed from the DEM (see 'Artifacts' under Bare Earth LiDAR/DEM Raster). When the identification of a feature such as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.

As described above, the collection of breaklines from lidar data is done in 3D stereo environment. This task includes collecting ponded bodies of water evident in the lidar at time of flight. The ponded water defined by the hydro breaklines does not necessarily indicate permanent, year-round presence of water bodies. The hydro break lines are collected to most accurately represent the ground surface for use in the generation of contours and digital elevation models.

Surface Models and Intensity Images

Digital Elevation Model (DEM)
A bare earth DEM will be provided for this project. To develop that dataset, the TIN's surface is referenced to determine the elevation for a highly dense set of points. The point sets will then be divided into cells. Each cell's

elevation will then be determined by an average of all the elevations sampled within its extent. The County prefers a DEM cell size that is 3.125 feet, such that the cells will exactly match the boundaries of each tile.

This process will be carried out for large overlapping blocks across the project area. The blocks will overlap to ensure consistency. After the countywide DEM dataset has been created, the large DEM files will be cut up into tiles based on the tiling scheme file and exported to ESRI Grid files or another format if preferred.

Once the DEM is created, visual inspection in Global Mapper is performed for artifacts (tension lines, voids, edge effects) and for hydro-enforcement of waterbody, hydrographic, island and soft features. If any artifacts appear in the DEM, the point sets will be reviewed to determine the cause of the problem. In addition, visual inspection will be performed on the DEM using Global Mapper and LP360 looking for floating breaklines in the surface.

Lastly, the DEM is inspected using Global Mapper and LP360 for .LAS filtering consistency, any remaining systematic issues, and to ensure vegetation has been removed from the surface.

Digital Surface Model (DSM)
Ayres Associates will generate a DSM for the County using the processed LiDAR data. The surface will be generated using TerraSolid and/or ESRI software, depending on the output format selected by the County. We will work with the County to determine the format that is best suited for the current GIS and mapping applications.

The processing technique for the DSM will be the same as described above for the DEM. Visual inspection is performed in Global Mapper and LP360 on the first return data to ensure that no “short range” data exists within the DSM.

The DSMs were created using first return lidar pulses, not including overlap points. The accuracy would be expected to be similar to that of the bare earth points on hard, flat, open surfaces such as parking lots. However, the DSM does not undergo the accuracy testing of the bare earth points, and is not subject to a vertical accuracy specification.

Intensity Images
LiDAR pulse return intensity images are created utilizing the GeoCue LiDAR 1 Cuepac. Lidar First Returns from the bare earth, vegetation, water, and building classes will be used in creating the images. Intensity is modulated within the “intensity” field of the .LAS file to create images that are quite similar to normal image-based orthos and can be used for planimetric feature compilation. Intensity images will be delivered by tile in GeoTIFF format (we can work with the County to produce alternative formats as needed). An automated script is used to validate that intensity values are integers ranging between 0 and 255. Another automated script is used to validate the header information on all of the GeoTiffs.

Visual inspection is performed in Global Mapper to identify any data voids and pixel gaps. Global Mapper is also used to check GeoTIFF header information to ensure the St. Croix County projection information is applied to each image correctly.

Contour Generation

Once all other base deliverable products have undergone the QA/QC process, have been completed, and have been approved by the county, the contour data set will be prepared. It is understood that St. Croix County requires two-foot contours.

Model keypoints will be generated as a subset of the bare earth surface. Model keypoints are files derived from the bare earth ground points using an intelligent data decimation algorithm. The algorithm works by thinning out the data in areas of little relief while keeping more points near breaks and variations in terrain. More information is retained using this method than compared to using a regularly-spaced grid, yet the process results in more manageable file sizes.

The hydro-flattened breaklines in combination with the model keypoints will be used to generate two-foot contours. All contours products will be produced using a combination of Terrasolid's TerraModeler and ESRI ArcGIS software and exported to AutoCAD and ESRI formats for delivery.

For this phase of the project, the following specifications are checked against:

- Model key points and hydro-flattened breaklines properly applied
- All contour features edge match adjacent tiles
- No contours shall cross or intersect and
- All contours have appropriately assigned elevations

QA/QC project tracking and reporting

Ayres Associates utilizes Project Manager & Project Dashboard software modules as part of its production workflow.

Project Manager is used to:

- Review top level information about a project and its status
- Assign individual technicians at the checklist step level to project entities
- Assign planned task execution times at the checklist step level
- Review detailed project statistics such as actual technician, actual production times and so forth

Project Dashboard is a web-application that allows the QA/QC supervisor to aggregate entities that are managed within a project into a project summary view.

Project Dashboard includes:

- Iconic display of project status
- Alternate display modes such as Phase variance, Phase schedule, External Financial System comparison
- User-settable alerts for Warning and Error conditions
- Microsoft Excel Import and Export of project definitions and status

Accuracy standard tests and checks

Data QC results are verified using survey checkpoints as well as any vertical checkpoints provided by the client to conduct an internal blind test of the vertical accuracy. The test within GeoCue is called a "z-probe". The z-probe results are reviewed by the Supervisor as well as a Certified Photogrammetrist to ensure that the vertical accuracy of the data meets or exceeds the specification. Any anomalies detected in the results are immediately investigated to determine the root cause, and corrective action is taken to mitigate any impact on schedule or quality.

In addition to the data being compared against survey checkpoints, various types of lidar derived images are created for terrain visualization. Examples of these include the following: delta elevation ortho (dz), which is used to assess the relative vertical accuracy of the flight lines. A second image is called color by flight line ortho, which is used to visualize the true ground coverage by flight line.

Metadata

All data produced by the Ayres Associates team will comply with the Federal Geographic Data Committee's (FGDC) Data Content and Process Standards. The FGDC, as lead entity in coordinating the National Spatial Data Infrastructure, has developed a set of standards that include specifications on description of processes, data content, classification, symbology, transfer and usability, and process standards. These standards include data collection, storage, and presentation of geospatial digital data.

To further ensure the compliance of the metadata produced by Ayres Associates, each file is processed through a third-party geospatial metadata validation service before it is finalized and delivered to the client.

LiDAR QA/QC Checklist – December 2014			
Milestone	**Production**	**Peer Review**	**Supervisor Review**
Flight plan and ground control (March 2013)	x	x	x
LiDAR data check-in	May 2014	May 2014	May 2014
As-flown coverage checks	x	x	x
Data density, overlap checks	x	x	x
GPS data checks	x	x	x
Accuracy Checks on LiDAR data	June-July 2014	June-July 2014	June-July 2014
Terrain visualization checks (dz ortho, color by flight line)	x	x	x
test for vertical accuracy (z-probe in LP360)	x	x	x
Review and pass for Automated Classification	x	x	x
Automated Classification Routine	Aug 2014	Aug 2014	Aug 2014
Review terrain for best automated routine for urban, rural	x	x	x
Review classification results for accuracy and consistency	x	x	x
Review and pass for Manual Classification	x	x	x
Manual Classification Routine	Sept 2014	Sept 2014	Sept 2014
Review Auto Classification for mis-classifications	x	x	x
Correct mis-classifications through manual edits	x	x	x
Review and pass full classification	x	x	x
QA checks for point cloud classification	x	x	x
Check point cloud compliancy with ASPRS LAS v1.2	x	x	x
Check against project-specific point classes	x	x	x
Check classification accuracy	x	x	x
All files projected and defined using Spatial Ref. Framework	x	x	x
Breakline development and checks	Aug-Sept 2014	Aug-Sept 2014	Aug-Sept 2014
Breakline differentiation review (linear vs. polygonal)	x	x	x
Hydro breakline classification (ponds, streams)	x	x	x
Hydro breakline checks for smooth, continuous, monotonic	x	x	x
Breakline review and pass for deliverable export	x	x	x
Contour generation and checks	Oct 2014	Oct 2014	Oct 2014
All base deliverables have passed QA/QC	x	x	x
Model key points/hydro-flattened breaklines properly applied	x	x	x
Contour smoothing routine properly applied (selected by County)	x	x	x
Review and pass for deliverable export	x	x	x
Metadata	Nov 2014	Nov 2014	Nov 2014
Metadata consisting of XML files for each dataset	x	x	x
All metadata consistent with the Federal Geographic Data Committee's Content Standards for Digital	x	x	x
Metadata includes processing steps and software used.	x	x	x
Final QA/QC	Nov 2014	Nov 2014	Nov 2014
Deliverables all pass individual QA/QC review	x	x	x
Deliverables exported to proper file format	x	x	x
Deliverables in proper coordinate reference system	x	x	x

Check and Test descriptions and expected results

As-flown coverage: Review as-flown flight line and coverage on the ground to ensure approximately 50% sidelap was achieved on each mission, extending to the 500-ft buffer around the County boundary.

Data density check: Review data density as collected throughout the project area to ensure it meets project specifications.

GPS data check: Review GPS data to make sure continuous coverage has been achieved within 30 km baseline length, remove any PDOP spikes above acceptable ranges, review satellite constellation and satellites in solution, review GPS timestamps for continuous data collection.

DZ ortho: Check vertical differences between flight lines to ensure line by line accuracy. The DZ ortho graphically represents relative accuracy within and between swaths at 5, 10, and15 cm increments. Any swaths that show a significant difference compared to adjacent flight lines are investigated and adjusted.

Color by flight line: This particular display is used as part of a qualitative workflow that helps better visualize and better understand the scan pattern, flight line orientation, flight coverage, and gives an additional confirmation that all point classes are present and seem to logically represent the terrain.

Z-probe: This process will compare any known (i.e surveyed) point or elevation data to the bare earth lidar surface. The survey checkpoint's XY location is overlaid on the TIN and the interpolated Z value is recorded. This interpolated Z value is then compared with the survey checkpoint Z value and this difference represents the amount of error between the measurements.

Point Cloud Classification: This process will ensure the removal of extraneous points and artifacts. Additionally, it will determine that all desired features have been retained within the data set. Filtered and edited data are subjected to rigorous QA/QC. A series of quantitative and visual procedures is employed to validate the accuracy and consistency of the filtered and edited data.

After the automated and manual edits are complete, the resulting accuracy of the bare earth classification will be as follows:

- 98% of Artifacts will be removed
- 98% of Outliers will be removed
- 98% of buildings will be removed
- 95% of vegetation will be removed

Breakline checks: Breaklines representing ponds and rivers will be smooth and continuous, and monotonic, and represent the water surface without any stair steps except for dams and rapids.

Contour smoothing: The default filtering parameters are applied for point spacing and smoothing. A check is then done to ensure the contour smoothing routine properly applied. Lastly, a check is done to ensure model key points and hydro-flattened breaklines were properly applied.

DEM check: Visual inspection in Global Mapper is performed for artifacts (tension lines, voids, edge effects) and for hydro-enforcement of waterbody, hydrographic, island and soft features. If any artifacts appear in the DEM, the point sets will be reviewed to determine the cause of the problem.

DSM check: Visual inspection is performed in Global Mapper and LP360 on the first return data to ensure that no "short range" data exists within the DSM.

Scope of Work Deliverables

LiDAR Data Deliverables

- Classified Lidar datasets in .LAS format and shapefile format
- Bare earth Lidar datasets in .LAS format and shapefile format
- 2-foot contours by tile in ESRI shapefile format
- Hydro-flattened breaklines by tile in ESRI shapefile format
- Project-wide DEM in ESRI GRID format
- Project-wide DSM in ESRI GRID format
- Project-wide intensity images in ESRI GRID format
- Ground control locations in ASCII format
- FGDC compliant metadata
- Tile schematic in ESRI shapefile format
- NSSDA/FEMA accuracy report in PDF format

Product Documentation and Reports

- Flight Plans and Proposed Ground Control: The Ayres Associates/Quantum Spatial team will submit flight plans and ground control locations to the County in ESRI shapefile format prior to the flight. The County will review and approve the plans prior to flight.

FEMA Accuracy Report

- As part of this LiDAR delivery, the County will provide independent ground control points – sufficient in number and appropriately placed so they serve as a compliant independent dataset with which Ayres Associates can test the LiDAR surface. After the analysis has been conducted by Ayres Associates, a FEMA accuracy report will be generated. The report will provide information about each survey point (location, ground type, etc.); a table showing each points elevation variance from the surface at that xy location; and the summary statistics (e.g., sum, average, and RMSE) that are the result of the test.

FGDC Metadata

- All data produced by the Ayres Associates team will comply with the Federal Geographic Data Committee's (FGDC) Data Content and Process Standards. The FGDC, as lead entity in coordinating the National Spatial Data Infrastructure, has developed a set of standards that include specifications on description of processes, data content, classification, symbology, transfer and usability, and process standards. These standards include data collection, storage, and presentation of geospatial digital data.

LiDAR Quality Control Plan supervised and reviewed by:

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