Calibration Procedures

Processing Procedures

Terrasolid's TerraMatch software was used to calculate and correct the IMU bore-site and mirror scale parameters for the Waushara County, WI LiDAR data. Within the TerraMatch software, the tie-line workflow was utilized to solve for heading, roll, pitch and elevation parameters. The tie-line workflow involves automated selection of numerous 'tie-lines', which represent a linear segment fit to the data that should have the same slope, azimuth, position and elevation, within the overlap sections of the survey and control lines. The tie-lines provide observations for algorithms within TerraMatch to solve for the bore-site and mirror scale parameters for each lift. The Tie-line workflow is dependent upon well distributed tie-lines throughout the swath point clouds to effectively solve for bore-site and mirror scale parameters with the automated algorithms. Tie-lines were generated using the calibration lines acquired over OSH for all three missions. TerraMatch quantified the mismatch associated with the tie-lines and provided descriptive statistics and adjustment parameters to apply to the raw LiDAR inputs. The adjustment parameters derived from this process were then applied to the planned flight lines acquired over the area of interest.

Quality Assurance Procedures

TerraScan was used to analyze relative fit between adjacent LiDAR survey lines as-well as with intersecting control flight swaths. Tie-lines were generated over the adjusted planned flight lines and analyzed to ensure that accuracy requirements were met. It was determined that a z correction per line was required to get the data within spec. The table below *(Table 1)* shows the Z correction applied to each flight line along with the statistics provided in the reportDrawing cross-sections in these overlapping regions within TerraScan software, allowed for analysis of locations such as rooftops, embankments and other locations to verify the effectiveness of the IMU bore-site and mirror scale adjustments made within TerraMatch. This process was repeated interactively until residual errors (*see Table 4 below*) between overlapping swaths, and across all project missions, were reduced to meet the accuracy requirement.

102	-0.038	109	0.102	203	-0.055	210	-0.03	304	-0.039
103	-0.034	110	0.142	204	0	211	-0.05	305	-0.084
104	-0.018	111	0.18	205	-0.043	212	-0.054	306	-0.037
105	-0.026	112	0.124	206	0.024	213	-0.045	307	-0.002
106	0.011	113	0.105	207	0.025	214	-0.006	308	-0.042
107	0.008	114	0.108	208	0.054	216	-0.077	311	0.062
108	0.1	117	-0.051	209	0.091	303	-0.098	313	-0.127

Table 1 Applied Z correction per flight (in feet)

After adjustment parameters were applied to each of the project flight lines, the overlap regions between flight lines were analyzed to assess relative accuracy. The elevation difference tool found in LP360 was used to generate DeltaZ files providing an image file depicting the offsets between flight lines by using a color range for the amount of offset found between the overlap areas. Table 2 below shows the color range settings used to generate the DeltaZ image files.

Intervals	Interval Size	Unit	
5	0.135	foot	☑ Absolute Values

Range	Color
> 0.54	Magenta
0.405 to 0.54	Blue
0.27 to 0.405	Red
0.135 to 0.27	Yellow
0 to 0.135	Green

Table 2 Delta Z and color range

After determining the relative accuracy or inter-swath goodness of fit in each overlap was acceptable, a vertical comparison of calibrated flight lines and the ground control was then performed. Upon review of the comparison results, it was determined that a Z shift in the amount of -0.6493 ft was required. The table *(Table 3)* below shows the comparison between ground control collected for the project and the final calibrated dataset with the Z shift applied.

GCP	Northing	Easting	Known Z	Laser Z	DZ
CAL009	2211951	784969.5	818.207	818.45	0.243
CAL012	2117768	743553.3	963.365	963.55	0.185
CAL001	2073936	814314.2	1071.832	1071.99	0.158
CAL019	2227691	727007.1	769.471	769.61	0.139
CAL004	2209189	812521.5	854.536	854.65	0.114
CAL013	2150178	764505	970.827	970.87	0.043
CAL020	2249056	724672.6	777.483	777.52	0.037
CAL014	2248037	759885.3	754.266	754.29	0.024
CAL010	2254926	819278.7	766.897	766.91	0.013
CAL007	2093198	777679	1088.784	1088.77	-0.014
CAL018	2166778	737335.7	836.342	836.32	-0.022
CAL011	2083414	760298.7	1096.214	1096.18	-0.034
CAL016	2099644	726799.6	945.776	945.72	-0.056
CAL006	2178743	788080.8	898.21	898.14	-0.07
CAL002	2101625	808030.2	1114.91	1114.84	-0.07
CAL017	2180387	754770	880.358	880.24	-0.118
CAL008	2195787	795460.4	855.367	855.24	-0.127
CAL005	2238212	803203	852.744	852.59	-0.154
CAL015	2220674	771404.7	923.767	923.58	-0.187
CAL003	2166033	801304.5	976.798	976.58	-0.218

Table 3 Control points and final applied laser difference (feet)

Flightline	Magnitude	Dz
102	0.0904	-0.0011
103	0.0901	-0.0005
104	0.0911	-0.0004
105	0.0922	0.002
106	0.0928	0.0015
107	0.093	-0.0019
108	0.0935	0.0038
109	0.0933	0.0034
110	0.093	-0.0056
111	0.0928	-0.0021
112	0.0931	0.0008
113	0.0945	-0.0033
114	0.0942	0.0026
117	0.0899	0.0058
203	0.0927	0.0019
204	0.0923	-0.0023
205	0.0924	0.0017
206	0.0913	-0.0016
207	0.0914	0.0007
208	0.0908	0.0004
209	0.0892	-0.0041
210	0.0929	0.0039
211	0.0926	0.0076
212	0.0927	-0.0027
213	0.0911	0.0068
214	0.0894	-0.0065
216	0.093	0.0026
303	0.0903	-0.0042
304	0.0902	-0.0035
305	0.0905	0.0029
306	0.0907	-0.0047
307	0.0914	0
308	0.0883	-0.006
311	0.093	0.0026
313	0.0914	0.0064

Table 4 Final swath overlap difference results

LiDAR Classification Procedures

Processing Procedures

Source LAS is imported into GeoCue with proper projection and datum set. Project coverage is observed against the desired boundary to verify coverage. A basic ground routine is done per line on a separate set of these tiles to use for dZ ortho rasters which when imported into GeoCue identifies swath-to-swath tie errors if they exist – where a certain color band in the images indicates numeric values of separation between each swath's ground plane. In addition, a dZ relative match table is output from TerraScan showing how well the dZ fit is between strips represented in magnitude and dZ. If the table doesn't present high error values and if the rasters pass within the desired color/numeric error range, further processing can proceed on the main tile set. If fail, reasons for the error must be deduced and more work on calibration may be needed. After calibrated swaths have passed testing, the ground macros can be run which identify low (Low Noise – 7) and high points (High Noise – 18), withheld points (W-class), and create the working ground set for further editing. Project control was run against the ground to evaluate the plane of the lidar data versus control and the LAS elevation was adjusted across all lines to best match control elevation. NVA testing was run against the raw swaths for initial proofing of the LAS elevation to pass QL2 requirements. After NVA testing passes, processing can proceed. Shapefiles of the control points, tile index, project boundary, trajectory data and swath index were created or edited in part by GeoCue and/or ArcMap with further attribution editing in ArcMap. Working tiles were cut from the source swaths into 5,000 ft X 5,000 ft tiles using GeoCue with all points set to Unclassified – 1 and exported for use in processing.

Below is the classification scheme required for Waushara County.

1 as Unclassified
2 as Bare earth
7 as Low noise
9 as Water
10 as Ignored ground
17 as Bridge deck
18 as High noise

Tiles are further observed for potential cloud or void areas before continuing, which could prohibit further processing. Manual ground-point editing proceeded on all tiles in effort to classify valid points into or out of the ground class (Bare Earth – 2). Neighbor tiles are loaded and editors apply Terrain Shaded Surface in TerraScan to search for anomalies of excess high ground points or for longer triangles which could indicate malformation of the ground where additional points are to be classified into ground from unclassified points. Points were also manually classified to remove bridge decks from the ground class over hydro features and put to a bridge deck class (Bridge Deck - 17) when identified.

Hydro breaklines (see Breakline_Processing document) were digitized at water elevation for any bodies of water over the entire project area including streams greater than 100ft in nominal width, water bodies greater than 2 acres in area, and islands greater than 1 acre. A macro was then run to classify points that lay at nominal water elevation to water class (Water – 9) that fell within the polygons representing bodies of water. Concurrently a 3-foot buffer zone around water polygons was derived from the ground class in TerraScan which put ground to a reserved ground class (Ignored Ground – 10). Upon completion of point classification, the overlap was cut in TerraScan which applies the appropriate overlap bit flag settings and an automated process was executed to remove any point outside of the provided project's buffered boundary from the project edge tiles.

Quality Control

Peer review of the edited tiles was completed. In another Q/C measure, LAS with edited ground class was imported into Global Mapper where an elevation grid was created of the project data using ground class data and hydro breaklines. Once the elevation grid was created the data was then exported into GeoTiff format at a desired resolution to sample elevation of the ground class where through the use of proprietary software highly errant ground points were flagged and poor signatures were resolved manually. All LAS points were run in TerraScan to report statistics and observe that all points landed on proper classification levels and that no points were removed from start to finish during processing. Further, DEM rasters were produced and as part of the testing of the classification, NVA testing was performed on these rasters. VVA testing was also performed on the classified LAS and the DEM rasters. This testing helped verify the LAS was classified to specification. As well, the DEMs were viewed in ArcMap and LP360 with the breaklines using terrain shading to empirically view and locate errant and poorly edited areas that got missed after routine editing. The fixes were made to the LAS and the rasters were recreated to reflect the updates. After Q/C, LAS files are repopulated in GeoCue to conform headers to correct project Coordinate Reference System. Repopulated tiles are then run through LAS Tools (LAS Info and LAS Validate) to observe proper header structure and header attribution.

Breakline Procedures

Processing Procedures

Water features were outlined using a combination of lidar stereo pairs created in GeoCue from LAS that had a ground class macro run on it and using LP360's terrain shading while referencing a set of LAS with ground classified. Ponds, streams, islands, and stream centerlines were collected by senior staff using stereo in Summit Professional and MicroStation and extracting in LP360 to a shapefile. Ponds were collected based on the size of being two acres or greater; streams collected were greater than one hundred feet in width; islands collected were one acre or greater. Z-accurate centerlines were collected on flowing water. The MicroStation file was then exported as a .dxf to load into ArcMap and combined with the LP360 shapefile to produce the merged shapefile hydro set. In ArcMap the Coordinate Reference System was set to NAD_1983_2011_StatePlane_Wisconsin_South_FIPS_4803_Ft_US. The *.dxf was loaded, the data was separated and converted into shapefiles for ponds, streams, islands, and centerlines. Shapefiles feature counts were then checked to make sure the same amount of ponds, steams, islands, and centerlines collected in MicroStation match those ultimately assembled and created in ArcMap as a shapefile.

Quality Assurance Procedures

Islands were clipped from ponds and streams to create a continuous feature. A Continental Mapping proprietary tool was used to check the monotonicity of each centerline. If there were any errors on a centerline shapefile another Continental Mapping proprietary tool was used to fix the monotonicity. An LP360 tool called *Flatten Rivers Polygon* was used to flatten streams to the elevation value prescribed by the centerline. The monotonicity of each stream shapefile was checked using a Continental Mapping proprietary tool. Then a Continental Mapping proprietary tool was used to fix the monotonicity of each stream shapefile that possessed an error. A Continental Mapping proprietary tool was used to check the elevations of each pond collected for absolute Z continuity. If there was an elevation change on a pond a Continental Mapping proprietary tool was used to flatten the pond. The stream shapefile and pond shapefile were combined into one breakline shapefile for further use in flattening the DEM grid. This shapefile was exported into a file geodatabase. Further Q/C of the breakline shapefile is made by thoroughly observing its appearance when used in conjunction with bare earth LAS after a test elevation grid is produced in Global Mapper.

DEM Procedures

Processing Procedures

Completely processed and quality-checked classified LAS files were imported into GeoCue Group's LP360 using the correct project Coordinate Reference System. A project-wide elevation grid was created using ground class data (Bare Earth – 2) and hydro-flattened breaklines were used to enforce the water elevation with ground points removed from within hydro polygons. Once the elevation grid was created the data was then exported into 5,000 X 5000 foot tiles of 32-bit Floating Point ERDAS Imagine format (.img) using 2-foot resolution per cell (per QL2 requirements) tiled to the project boundary. The resulting *.img files are then loaded into ArcMap to test for proper coordinate projection, data integrity, and attributes.

Quality Assurance Procedures

A Continental Mapping proprietary tool was used to Q/C. This tool checks for abnormal spikes and mismatched elevation values that would affect the DEM output in a previous Q/C step. NVA and VVA testing was performed on the rasters. This testing helped verify the LAS was classified to specification and subsequently that the resultant DEMs fit known control to specification. As well, the DEMs were viewed in ArcMap and LP360 with the breaklines using terrain shading to empirically view and locate errant and poorly edited areas that got missed after routine editing. Attention was given to view the interaction of the ground data adjacent to the breaklines such that no ground points were left within the hydro polygons nor breakline elevations exceeded the height of surrounding terrain. Apparent errors would visually appear as an unexpected terrain color change to the viewer. Suspect outliers and errors were reviewed and fixes were made to the LAS as needed. The specific rasters were recreated to reflect the updates and re-checked for approval. VVA testing @ 95% Confidence Level was 24.7cm