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Project Name: LiDAR Survey of Iowa River Flood, Iowa City June 2008, and the Clear Creek Watershed

1. LiDAR System Description and Specifications

This survey used an Optech GEMINI Airborne Laser Terrain Mapper (ALTM) serial number 06SEN195 mounted in a twin-engine Cessna Skymaster (Tail Number N337P).

Operating Altitude	150 - 4000 m, Nominal
Horizontal Accuracy	1/5,500 x altitude (m AGL); 1 sigma
Elevation Accuracy	5 - 30 cm; 1 sigma
Range Capture	Up to 4 range measurements, including 1st, 2nd, 3rd, last returns
Intensity Capture	12-bit dynamic range for all recorded returns, including last returns
Scan FOV	0 - 50 degrees; Programmable in increments of ±1degree
Scan Frequency	0 – 70 Hz
Scanner Product	Up to Scan angle x Scan frequency = 1000
Roll Compensation	±5 degrees at full FOV – more under reduced FOV
Pulse Rate Frequency	33 - 167 KHz
Position Orientation System	Applanix POS/AV 510 OEM includes embedded BD950 12-channel 10Hz GPS receiver
Laser Wavelength/Class	1047 nanometers / Class IV (FDA 21 CFR)
Beam Divergence nominal (full angle)	Dual Divergence 0.25 mrad (1/e) or 0.80 mrad (1/e)

Table 1 – Optech GEMINI specifications.

See http://www.optech.ca for more information from the manufacturer.

2. Survey area

The two survey areas are both irregular polygons. The first polygon was approximately 67 km long and averaged approximately 4.5 km wide (300 square km), and was centered on the Iowa River from the Coralville Dam just north of Iowa City, Iowa and continuing south. The second polygon enclosed 282 km square and was centered on the Clear Creek Watershed. Both survey polygons are shown below (outlined in blue) in Figure 1.

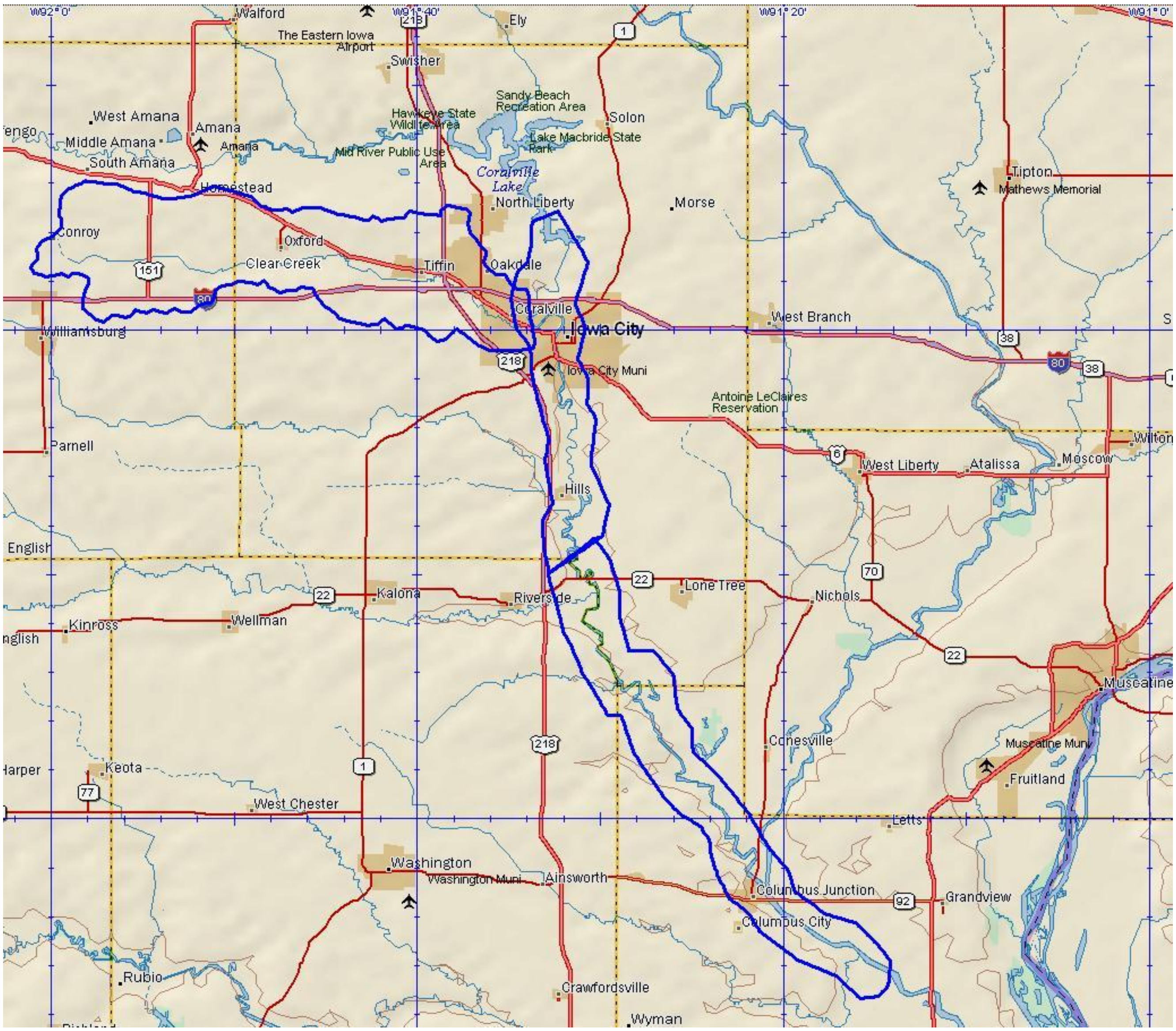

Figure 1 – Shape and location of the survey polygons. Total area = 582 km square.

3. Survey Times

This survey was flown in eight survey flights: two on June 19, 2008 (day-of-year 171), three flights on June 20, 2008 (172) and three flights on June 21 (173). The survey required a total of 15.8 hours of laser-on time and 27.2 hours of total flying time.

The individual flights are summarized below in Table 2.

Flight #	Date	GMT Begin	GMT End	Laser-On Time	Area Flown
1	19 June 2008	12:30	15:30	1.7	Iowa River
2	19 June 2008	21:05	02:07	3.1	Iowa River
3	20 June 2008	13:10	14:55	0.7	Iowa River
4	20 June 2008	16:15	19:45	1.9	Iowa River
5	20 June 2008	20:55	22:25	0.6	Iowa River
6	21 June 2008	12:30	15:30	1.7	Clear Creek
7	21 June 2008	16:00	20:00	2.7	Clear Creek
8	21 June 2008	21:10	02:40	3.4	Both Areas

Table 2 – Flight dates and times.

Local time is CST (Central Standard Time) and is equal to GMT – 6.0 hours.

Survey Parameters

The Iowa River survey required 60 flight lines shown below in Figure 2.

The Clear Creek Watershed required 46 flight lines shown below in Figure 3.

Flight parameters for the both surveys were the same and are shown in Figure 4.

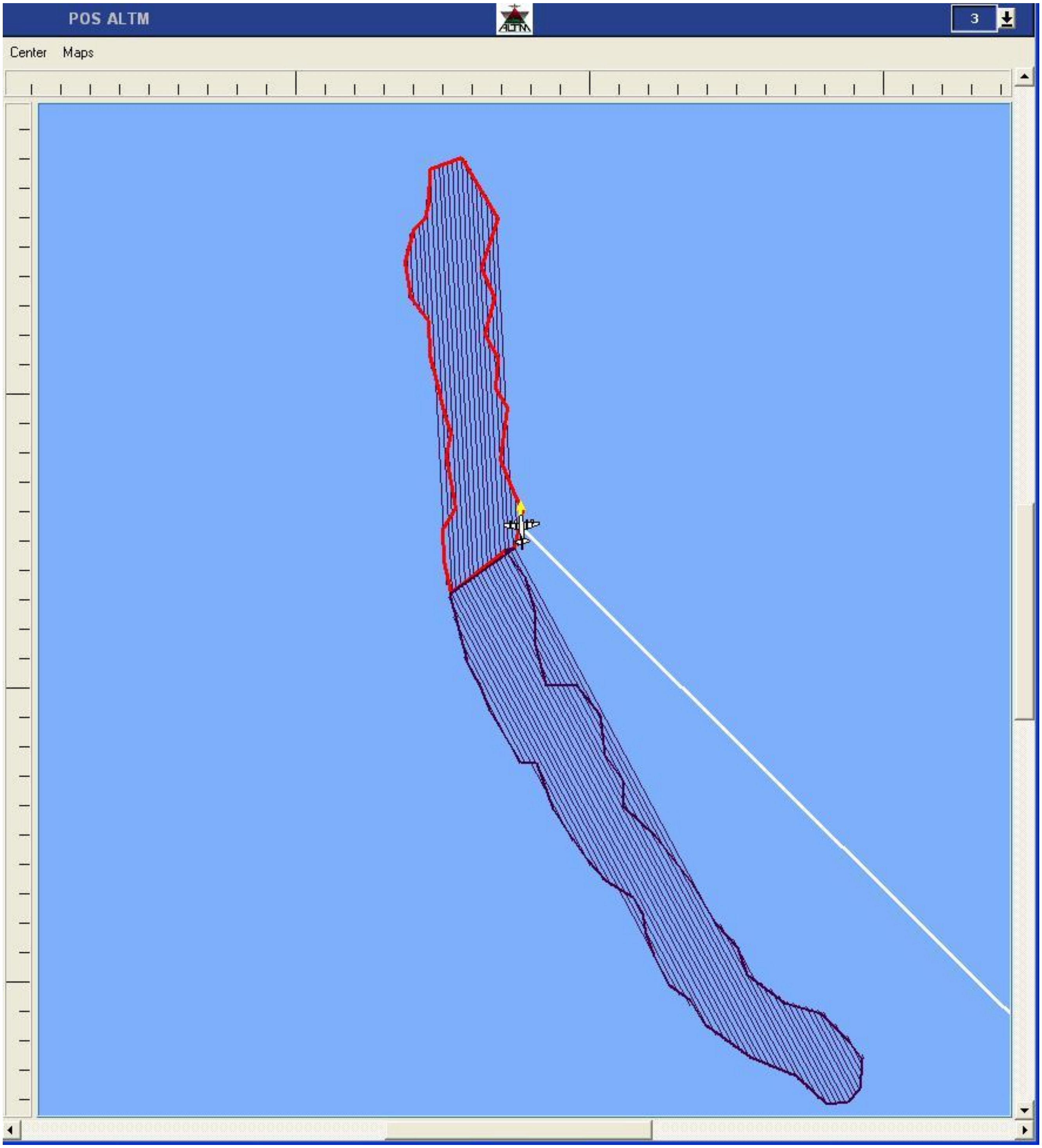

Figure 2 - Iowa River Flight Lines

Figure 3 - Clear Creek Watershed Flight Lines.

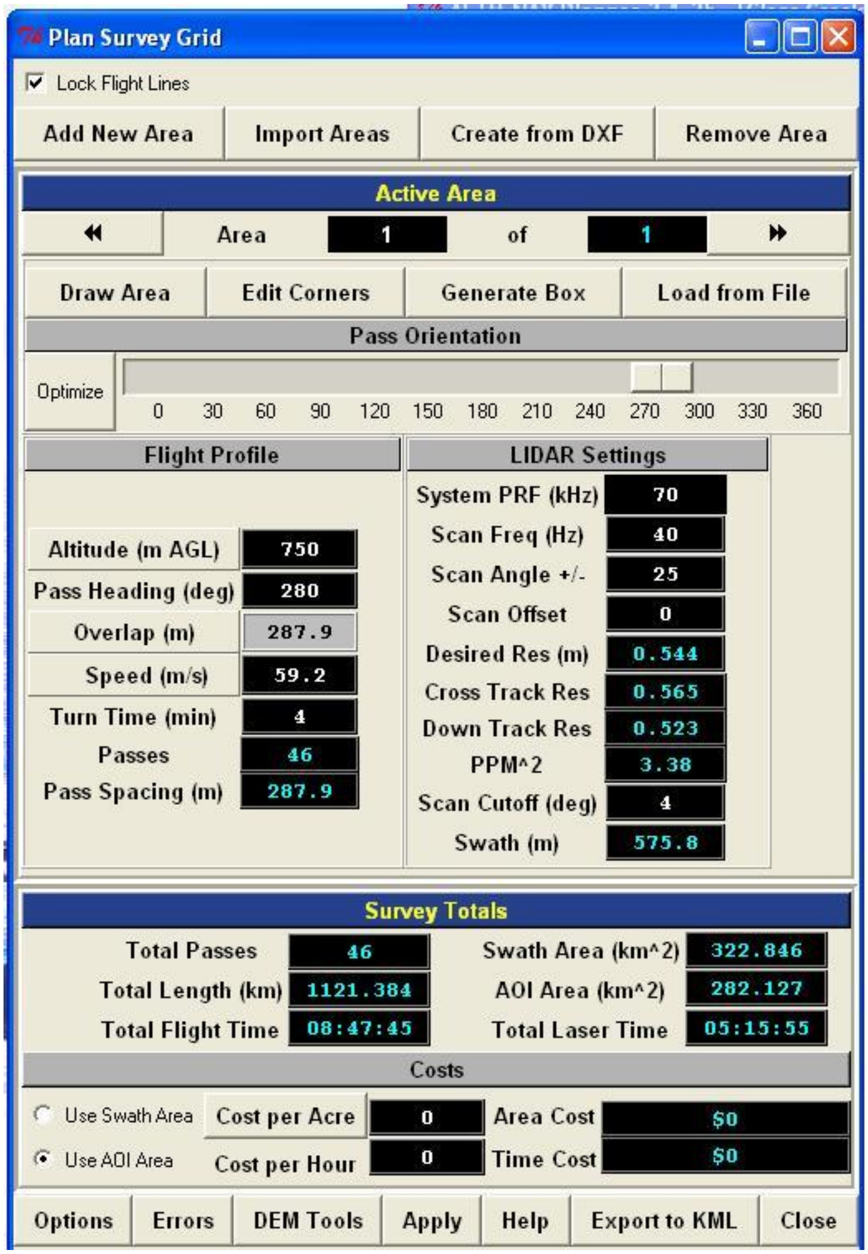

Figure 4 - Survey Parameters.

Note that the swath width of a single pass is 576 meters (nominal), and that line spacing was planned at 287 meters.

Planned overlap was 100% (50% side-lap) or 287 meters per swath. Pulse rate frequency was set at 70 KHz.

Point density over land (no water) averaged approximately 4.5 points per square meter; point density over water was more variable and much less: between approximately 1 and 1.5 points per square meter. This is due to off-nadir shots on water yielding no return. Very high and very low intensity shots were NOT filtered out in order to preserve all observations: note that the vertical accuracy of these shots may be lower.

Survey totals appear below in Table 3.

Survey Totals	
Total Passes	106
Total Length	2249 km
Total Flight Time	27.2 hrs
Total Laser Time	15.8
Total Swath Area	659 km^2
Total AOI Area	582 km^2

Table 3 – Survey totals. Area of Interest is abbreviated AOI.

LiDAR settings are shown in Table 4.

LiDAR Settings	
Scan Frequency	40 Hz
Scan Angle	+/- 25 deg
Scan Cutoff	+/- 4.0 deg
Scan Offset	0 deg
System PRF	70 kHz
Swath Width	576 m

Table 4 – LiDAR settings.

In summation, the point density was higher over land than over water. Scan frequency was held to 40 Hz and the scan angle limited to +/- 21 degrees or less in processing.

5. GPS Reference Stations

Four GPS reference station locations were used during the survey, three of which were newly established NCALM stations. One station (named IOWA) was set at the Iowa City Municipal Airport, one in the city center of Oxford (OXF_), and one 6 km south of Lone Tree (CORN). In addition to the NCALM stations, the CORS NLIB in North Liberty was also used.

All NCALM reference GPS observations were logged at 1 Hz. NLIB log rate was 5 seconds. Reference coordinates for the three NCALM stations are derived from multiple observation sessions submitted to the NGS on-line processor OPUS which processes static differential baselines tied to the National CORS network. The repeat OPUS solutions for all NCALM stations yielded reference station coordinate solutions with differences less than 0.010 meters in both horizontal and vertical components. For further information on OPUS see http://www.ngs.noaa.gov/OPUS/ and for more information on the CORS network see http://www.ngs.noaa.gov/CORS/ .

Ground equipment consisted of ASHTECH (Thales Navigation) Z-Extreme receivers, with choke ring antennas (Part# 700936.D) mounted on 1.5-meter fixed-height tripods. The airborne receiver is an integrated GPS receiver module Trimble BD950, logging at 10 Hz. See Appendix B for the OPUS solutions of NCALM stations.

Figure 5 (below) is a map showing the locations of the GPS reference stations.

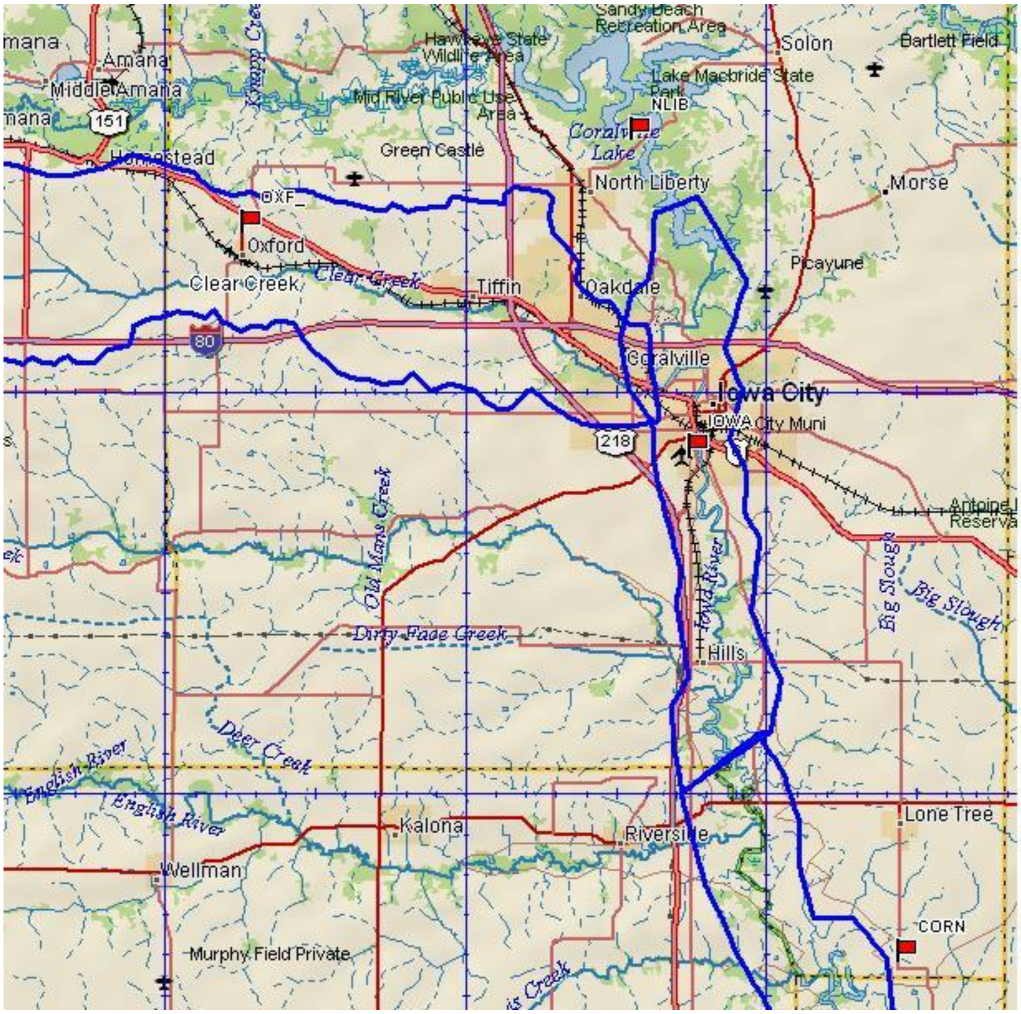

Figure 5 - Red Flags show locations of GPS reference stations used for trajectory processing.

6. Navigation Processing

Dr. Gerald Mader of the NGS Research Laboratory was contracted to process the trajectories for this survey using his KARS software (Kinematic and Rapid Static). KARS kinematic GPS processing uses the dual-frequency phase history files of the reference and airborne receivers determine a fixed integer ionosphere-free differential solution.

The aircraft trajectories for the survey flights on both days were processed separately using all available reference stations and then positional differences between the separate solutions were plotted.

Figure 6 (below) is a plot of the differences in Easting, Northing, and Height of the June 19 flight 2 trajectory processed from the two different reference stations (IOWA and CORN). These results are typical for all flights in this survey.

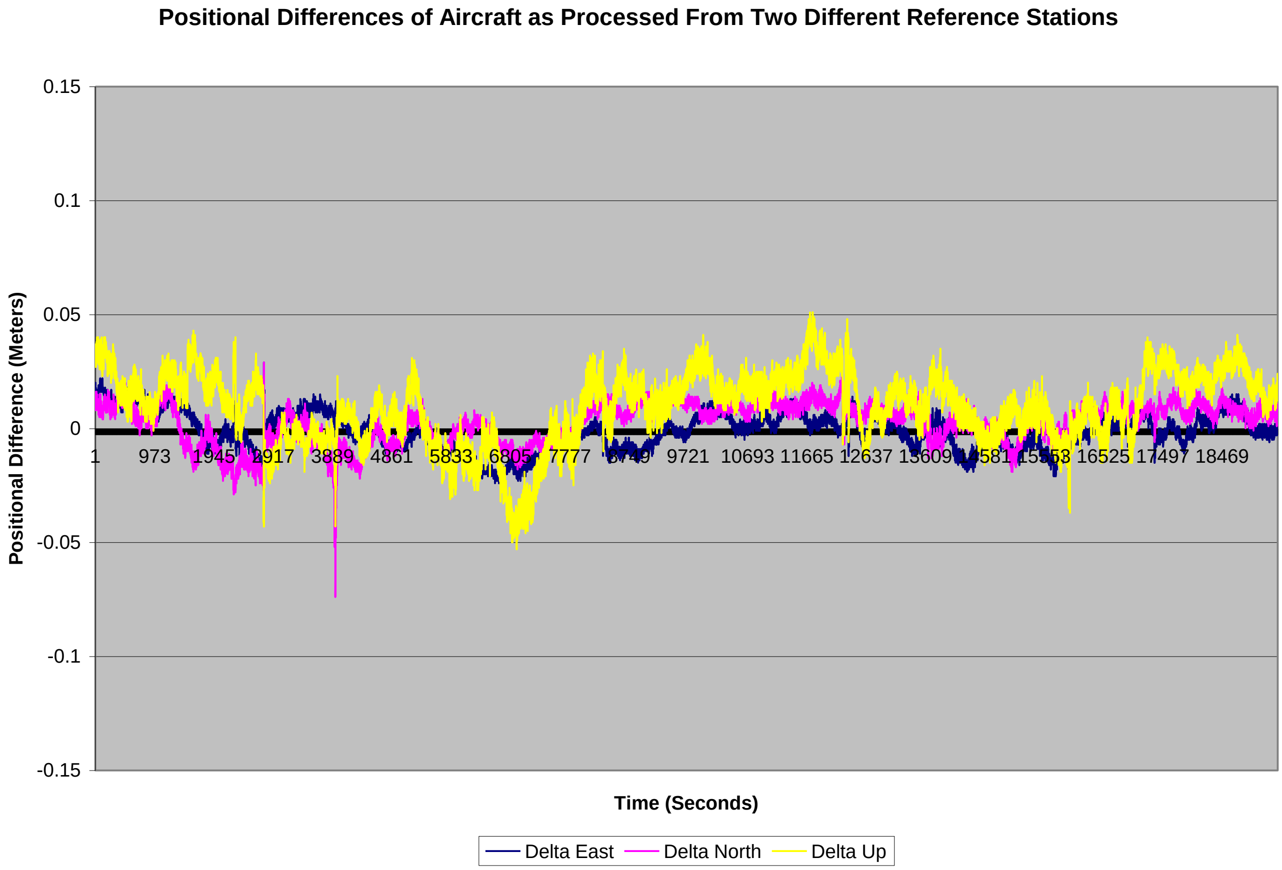

Figure 6 - Positional differences in aircraft trajectories with respect to time as processed from IOWA and CORN

The standard deviation of the differences in the easting position of these two trajectories is 8 mm, in northing 9 mm, and in height 16 mm. Aircraft trajectory position files are available in ASCII format, 4-columns, GPS Time (Seconds of the week); Easting; Northing; Height. These aircraft trajectory files will be sent by e-mail if requested.

After GPS processing, the trajectory and the inertial measurement unit (IMU) data collected during the flights were input into APPLANIX software POSPac (Version 4.3) which implements a Kalman Filter algorithm to produce a final, smoothed, and complete navigation solution including both aircraft position and orientation at 200 Hz. This final navigation solution is known as the SBET (Smoothed Best Estimated Trajectory). The SBET and the raw laser range data were combined using Optech's DashMap (Version 3.005) processing program to generate the laser point dataset in LAS format.

7. Calibration, Validation, and Accuracy Assessment

Two types of calibration procedures were used on this project: relative calibration and absolute calibration.

Relative calibration was computed for each flight by surveying crossing flight-lines over the project flight lines and using TerraMatch software (http://www.terrasolid.fi/en/products/4). TerraMatch finds the best-fit values for roll, pitch, yaw, and scanner mirror scale by analyzing the height differences between computed laser surfaces from individual crossing and/or overlapping flight lines.

Absolute calibration was done by establishing a calibration site consisting of 1237 check points surveyed with vehicle-mounted GPS over 1.7 kilometers of paved surfaces on a local road 1 km southwest of the Airport. The section of road containing these check points was then surveyed with crossing flight lines using the ALTM. This was repeated on each survey flight. After comparing the heights of the check points with their nearest neighbor LiDAR shot a systematic height bias (less than 20 cm) was calculated and removed by applying a range correction calibration parameter during processing.

The heights of several thousand LiDAR shots were compared with the height of their nearest-neighbor check point on the calibration surfaces over all of the 8 survey flights. The standard deviation of these height differences was consistent and averaged less than 0.030 meters.

Absolute calibration analysis can also yield an accuracy assessment for hard surfaces. The aircraft maintained a flying height of approximately 750 meters Above Ground Level (AGL) while surveying cross lines above the calibration site, and fired the laser at 70 KHz, the same parameters that were maintained over the project polygon. It is reasonable to use this standard deviation (0.030 meters) calculated for the calibration site as a vertical accuracy assessment (1-sigma) to similar hard surfaces on the project polygon.

8. Laser Point Processing

All coordinates were processed with respect to NAD83 and referenced to the national CORS network. The projection is UTM Zone 15, with units in meters. Heights are NAVD88 orthometric heights computed using NGS GEOID03 model. The flight strip point cloud files were tiled into 1 kilometer square blocks with a naming convention using the lower left coordinate (minimum X, Y) as the seed for the file name as follows: XXXXXX_YYYYYYY. The flight identifier is included for time information on the changing water level. For example if the tile bounds coordinate values from easting equals 622000 through 623000, and northing equals 4597000 through 4598000 then the tile filename is 622000_4597000. This is illustrated below in Figure 7.

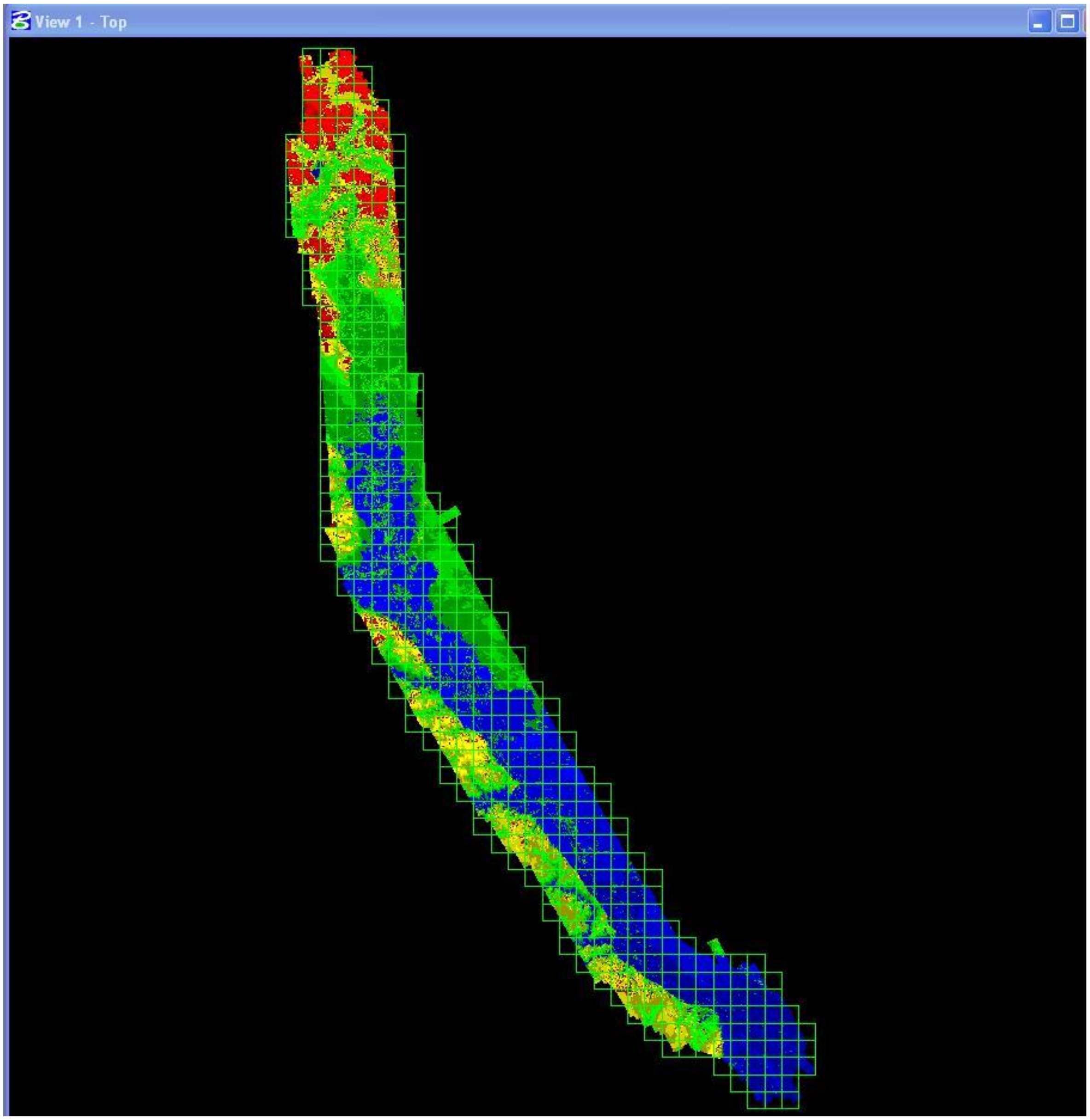

Figure 7 - Tile footprints overlaid on the point cloud colored by elevation.

Similar tiles were created for the Clear Creek Watershed. These tile footprints are available as an AutoCAD DXF or ESRI shape file.

During processing, a scan cutoff angle of 4.0 degrees was used to eliminate points at the edge of the scan lines. This was done to improve the overall DEM accuracy as points farthest from the scan nadir are the most affected by small errors in pitch, roll and scanner mirror angle measurements.

9. Classification

TerraSolid's TerraScan software was used to classify the raw laser point into the following categories: ground, non-ground (default), aerial points and low points.

Because of the large size of the LiDAR data the processing had to be done in tiles. Each survey segment was imported into TerraScan projects consisting of 1000m x 1000m tiles aligned with the 1000 units in UTM coordinates.

The classification process was executed by a TerraScan macro that was run on each individual tile data and the neighboring points within a 20m buffer. The overlap in processing ensures that the filtering routine generate consistent results across the tile boundaries.

The classification macros consist of a core of three algorithms:

1) *Removal of "Low Points"*. This routine was used to search for possible error points which are clearly below the ground surface. The elevation of each point (=center) is compared with every other point within a given neighborhood and if the center point is clearly lower then any other point it will be classified as a "low point". This routine can also search for groups of low points where the whole group is lower than other points in the vicinity. Input parameters used were:

Search for: Groups of Points
Max Count (maximum size of a group of low points): 6
More than (minimum height difference): 0.3 m
Within (xy search range): 5.0 m

2) *Ground Classification*. This routine classifies ground points by iteratively building a triangulated surface model. The algorithm starts by selecting some local low points assumed as sure hits on the ground, within a specified windows size. This makes the algorithm particularly sensitive to low outliers in the initial dataset, hence the requirement of removing as many erroneous low points as possible in the first step.

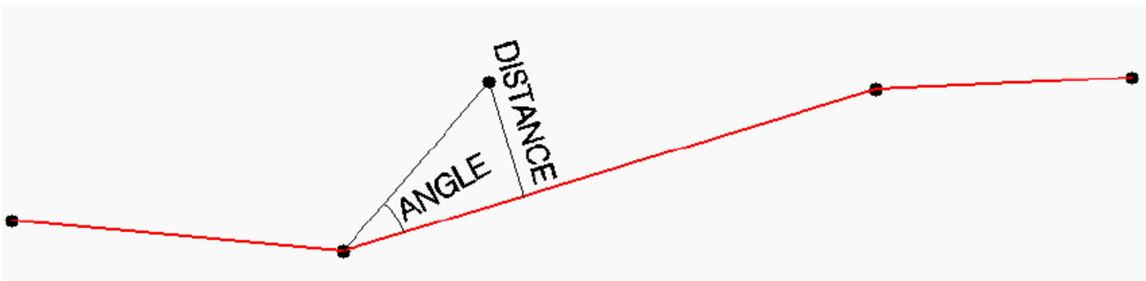

Figure 6 Ground classification parameters

The routine builds an initial model from selected low points. Triangles in this initial model are mostly below the ground with only the vertices touching ground. The routine then starts molding the model upwards by iteratively adding new laser points to it. Each added point makes the model follow ground surface more closely.

The various input parameters are
Max Building Size (window size):

Max Terrain Angle: The terrain
Iteration Angle
Iteration Distance

These parameters depend on the properties of the area such as extent of urbanization, vegetation density and terrain (flat/rugged). Iteration parameters determine how close a point must be to a triangle plane so that the point can be accepted to the model. Iteration angle is the maximum angle between point, its projection on triangle plane and closest triangle vertex. The smaller the Iteration angle, the less eager the routine is to follow changes in the point cloud. Iteration distance parameter makes sure that the iteration does not make big jumps upwards when triangles are large. This helps to keep low buildings out of the model.

3) *Below Surface removal*. This routine classifies points which are lower than other neighboring points and it is run after ground classification to locate points which are below the true ground surface. For each point in the source class, the algorithm finds up to 25 closest neighboring source points and fits a plane equation through them. If the initially selected point is above the plane or less than “Z tolerance”, it will not be classified. Then it computes the standard deviation of the elevation differences from the neighboring points to the fitted plane and if the central point is more than “Limit” times standard deviation below the plane, the algorithm will classify it into the target class.

Below Surface classification parameters used:

Source Class: Ground
Target Class: Low Point
Limit: 8.00 * standard deviation
Z tolerance: 0.10 m

10. DEM Production

The point data is output from TerraScan in 1000m x 1000m tiles, with 20m overlap. Two sets of files are generated, in XYZ ASCII format: filtered (ground class) and unfiltered (ground and “default” classes). In the unfiltered dataset the outlier classes are excluded from output (aerial and low points). The overlap is needed in order to generate a consistent interpolation across tile edges and it will be trimmed in the final tile DEMs.

The point tiles are gridded using Golden Software’s Surfer 8 Kriging at 1.0m cell size, using a 5m search radius for the unfiltered point data and 10m for the filtered.

The gridding parameters are:

Gridding Algorithm: Kriging
Variogram: Linear
Nugget Variance: 0.15 m
MicroVariance: 0.00 m
SearchDataPerSector: 7
SearchMinData: 5
SearchMaxEmpty: 1
SearchRadius: 5m (unfiltered), 10m (filtered)

The resulting tiled Surfer grid sets are transformed using in-house Perl and AML scripts into ArcInfo binary seamless tiles at 0.5m cell size. Due to the large area covered by the segments and the ArcInfo software limitations it is not possible to create one large mosaic for the entire area so the 1.0m tiles are mosaiced at 1m resolution into 10Km wide segments.

11. Available Deliverables

Available deliverables include all of the following data products:

1. Flight Strips (LAS format).
2. 1 KM Tiles (LAS format) – per flight – classified and unclassified.
3. 1 KM Tiles (ASCII format) – per flight – classified and unclassified.
4. ESRI DEMs, (1m x 1m) -per flight - classified and unclassified.
5. Surfer Binary Grids, - per flight - classified and unclassified.