July 25, 2005

Project Report
City of Arlington

Contract #2297-H

Report Presented to:

City of Arlington Development Services
238 North Olympic Avenue
Arlington, WA 98223
Phone: (360) 403-3536
Fax: (360) 403-3447

1.Project Overview

Field Crew:

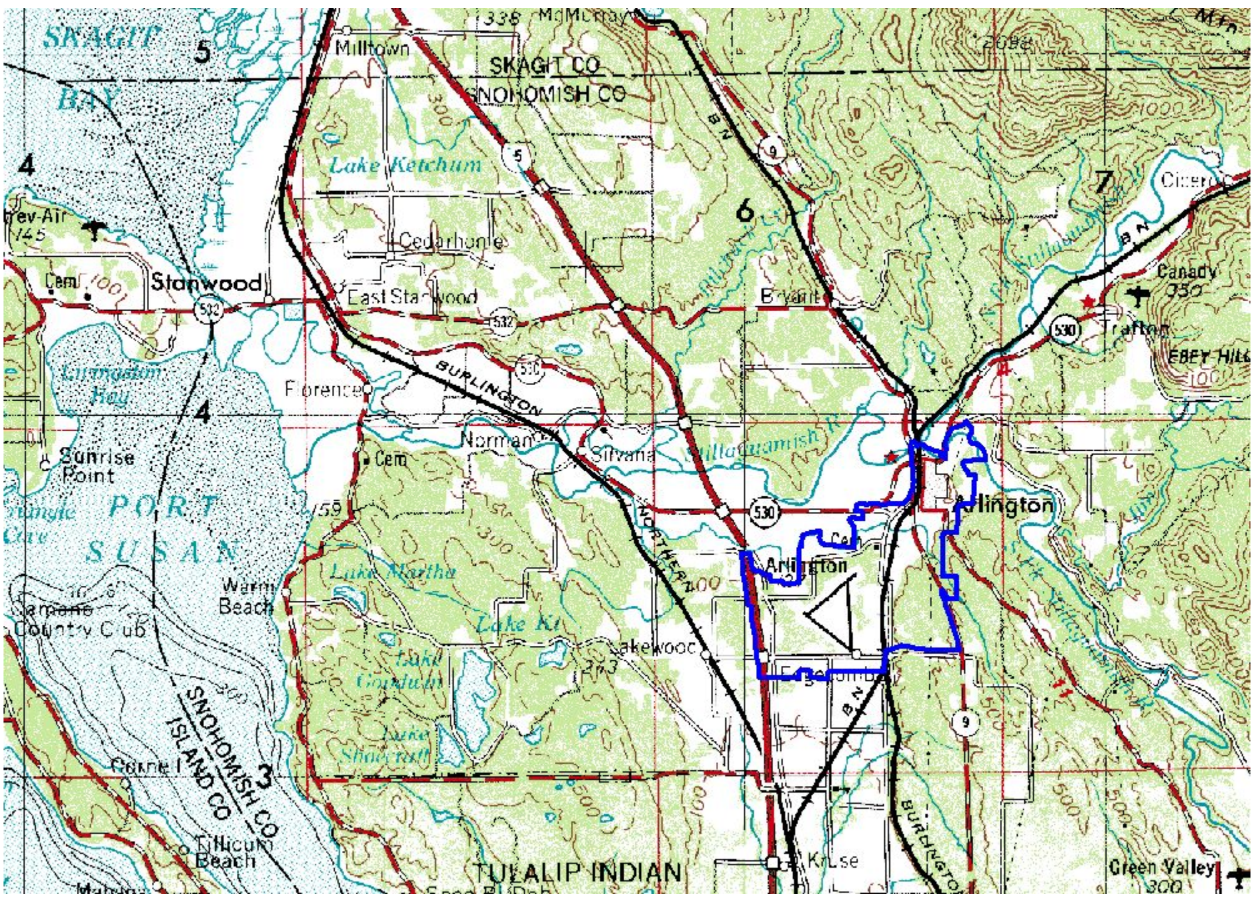
The Terrapoint field crew consisted of Todd Mitchell, field project manager and Barry Kaser, LIDAR operator. The Aries Aviation aircraft crew consisted of Andre Bourque, pilot and Bob Passon, flight engineer.

Post Processing Crew:

Todd Mitchell completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Brian Herring and Joe Sackett.

Size of Project:

The project site covered approximately 10 square miles, as identified in the following image:



Location:

The project area is located in Snohomish County Washington .

Project Type:

The purpose of this project is to provide a high quality DEM of the site for City of Arlington.

Approximate Duration of Project:

The field data collection took place from Feb. 23rd to Feb. 26th, 2005. The control network and check point surveys were performed on Feb. 28th, 2005.

Calibration, vegetation removal and product generation took place from April 15th to June 15th, 2005.

Number of Flights:

Two flights were required to cover the project area with 22 flight lines.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (1998) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS monuments, including PID AE1858 and temporary Terrapoint monument ARL1. Kinematic GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of all control coordinates is given in Table 1.

25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
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Table 1: Control and Base Coordinate							
NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
AE1858	48	16	23.39780	-121	39	34.13741	142.6619
ARL1	48	09	27.37695	-122	09	50.17267	16.6241

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

A Navajo twin-engine aircraft (C-GQVP) was used for this project. The aircraft was based out of Arlington Municipal Airport. The Navajo was typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Two Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
   +/- 15-20 centimeters on Hard Surfaces (roads and buildings)

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+/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
+/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
+/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 1101 kinematic checkpoints collected along two roadways within the project site yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison	
Average dz	-0.021
Minimum dz	-0.200
Maximum dz	0.160
Average magnitude	0.050
Root mean square	0.063
Std deviation	0.059

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

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The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAR data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

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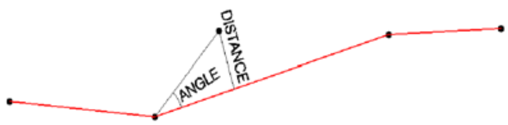

Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

Data delivered in format:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)

Bare Earth Point Data (DTM)

Data delivered in two formats:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

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All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code (G = Ground, V = Vegetation/Non-Ground, S = Building/Structure, N = Vegetation or Building, B = Blunder)

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

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December 15, 2005

Project Report

Washington Department of Natural Resources

Lake Cavanaugh

Contract #2292-H

Report Presented to:

Washington Department of Natural Resources
Resource Mapping Section
1111 Washington Street SE
Olympia, WA 98504-7032
Point of Contact: Terry Curtis
Phone: (360) 902 – 1210
Fax: (360) 902 – 1778
E-mail: terry.curtis@wadnr.gov

1.Project Overview

Field Crew:

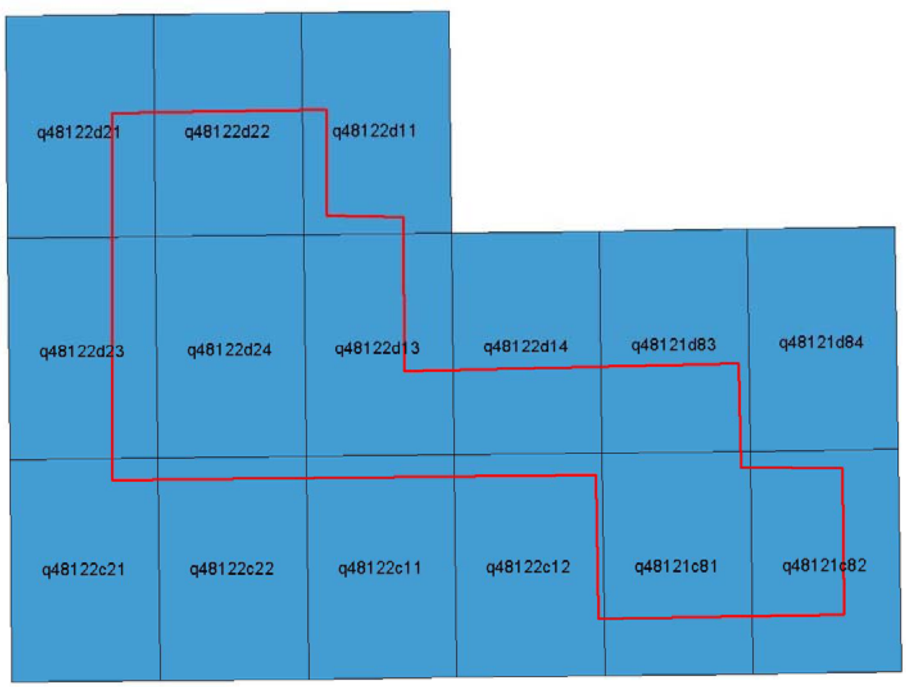
The Terrapoint field crew consisted of John Anderson, field project manager and Todd Mitchell and Louis Hill, LIDAR operators. The Aries Aviation aircraft crew consisted of Rory Clayton, Andre Bourque, pilots and Bob Passon, flight engineer.

Post Processing Crew:

John Anderson completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Andrew Pace and Joe Sackett.

Size of Project:

The project site covered approximately 62 square miles, as shown in the following image.



Location:

The project area is located in Skagit County Washington .

Project Type:

The purpose of this project is to provide a high quality DEM of the site for the Washington Department of Natural Resources.

Approximate Duration of Project:

The field data collection took place from April 6th to April 10th, 2005. The control network and check point surveys were performed from April 9th to 11th, 2005.

Calibration, vegetation removal and product generation took place from August 15th to November 25th, 2005.

Number of Flights:

Three flights were required to cover the project area with 58 flight lines. An additional, fourth flight was added to fill in areas with low data density.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (1998) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS monument PID TR2547 and WSDOT monument WS1945. Kinematic and Static GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of all control coordinates is given in Table 1.

Table 1: Control and Base Coordinate							
NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
TR2547	48	09	42.67994	-122	10	12.44883	17.4394
WS1945	48	25	48.28410	-122	15	52.35410	11.443

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

Two Navajo twin-engine aircraft (C-FVZM and C-GQVP) were used for this project. The aircraft were based out of Arlington Municipal Airport. The Navajo were typically flown at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using one 20 kHz (C-GZVP – Unit 5) and one 40 kHz (C-FVZM – Unit 6) ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The systems consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Three Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

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1. Absolute Vertical Accuracy:
   +/- 10-15 centimeters on Hard Surfaces (roads and buildings)
   +/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
   +/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
   +/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy (as agreed with CUSTOMER):
   1 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, static and kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 10 static checkpoints yielded the results given in Table 2 (values in meters).

Table 2: Static Control Comparison

Pt ID	Easting	Northing	Elevation	Laser Elev.	dZ
2322gt01	554430.926	5364410.367	32.989	33.010	0.021
2322gt02	552428.431	5364995.029	16.153	16.050	-0.103
2322gt03	552818.780	5364674.742	23.032	22.990	-0.042
2322gt04	552887.327	5367376.170	37.290	37.330	0.040
2322gt06	555357.567	5366150.417	15.969	15.950	-0.019
2322gt07	554807.040	5366357.346	13.333	13.400	0.067
2322gt08	554389.799	5366738.601	12.043	12.100	0.057
2322gt09	553157.202	5367220.868	23.021	23.070	0.049
DH212	554407.742	5364965.546	37.257	37.500	0.243
WS1945	554404.085	5364364.745	33.698	33.660	-0.038

Average dz	0.028
Minimum dz	-0.103
Maximum dz	0.243
Average magnitude	0.068
Root mean square	0.092
Std deviation	0.093

A comparison of LIDAR data with 278 kinematic checkpoints yielded the results given in Table 3 (values in meters).

Table 3: Kinematic Point Comparison	
Average dz	-0.019
Minimum dz	-0.156
Maximum dz	0.123
Average magnitude	0.036
Root mean square	0.046
Std deviation	0.042

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAr data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

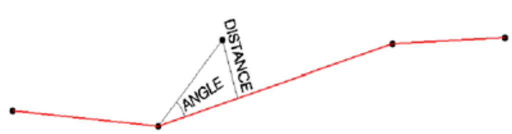


Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

Data delivered in format:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)

Bare Earth Point Data (DTM)

Data delivered in two formats:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity

- Classification Code (G = Ground, V = Vegetation/Non-Ground, S = Building/Structure, N = Vegetation or Building, B = Blunder)

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

June 28, 2005

Project Report
City of Snohomish

Contract #2299-H

terrapoint

Report Presented to:

City of Snohomish
116 Union Avenue
Snohomish, WA 98290-2994
Point of Contact: Renee LaPointe
Phone: (360) 568-3115
Fax: (360) 568-1375

1.Project Overview

Field Crew:

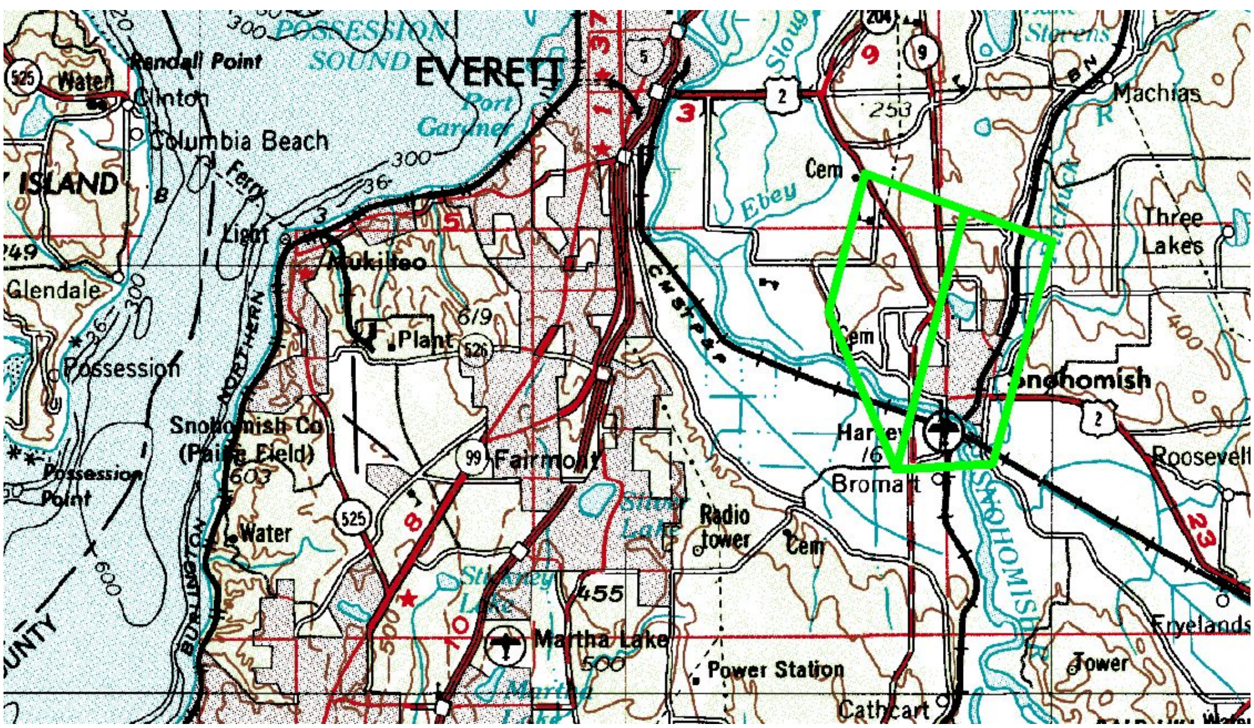
The Terrapoint field crew consisted of Todd Mitchell, field project manager and Barry Kaser, LIDAR operator. The Aries Aviation aircraft crew consisted of Andre Bourque, pilot and Bob Passon, flight engineer.

Post Processing Crew:

Todd Mitchell completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Brian Herring and Joe Sackett.

Size of Project:

The project site covered approximately 6 square miles, as identified in the following image:



Location:

The project area is located in Snohomish County Washington .

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Project Type:

The purpose of this project is to provide a high quality DEM of the site for City of Snohomish.

Approximate Duration of Project:

The field data collection took place on Feb. 26th, 2005. The control network and check point surveys were performed on Feb. 28th, 2005.

Calibration, vegetation removal and product generation took place from April 15th to June 15th, 2005.

Number of Flights:

One flight was required to cover the project area with 20 flight lines.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (1998) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

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ARL1	48	09	27.37695	-122	09	50.17267	16.6241

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

A Navajo twin-engine aircraft (C-FVZM) was used for this project. The aircraft was based out of Arlington Municipal Airport. The Navajo was typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

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4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
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+/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
+/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
   +/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
   2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 518 kinematic checkpoints collected along two roadways within the project site yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison	
Average dz	-0.003
Minimum dz	-0.270
Maximum dz	0.220
Average magnitude	0.062
Root mean square	0.075
Std deviation	0.075

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

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6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

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The Woodlands, TX 77380
Phone: (218) 364 – 4080
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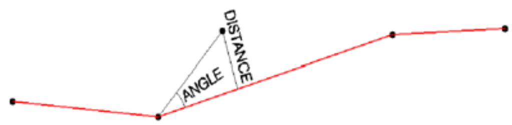


Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

Data delivered in format:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)

Bare Earth Point Data (DTM)

Data delivered in two formats:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code (G = Ground, V = Vegetation/Non-Ground, S = Building/Structure, N = Vegetation or Building, B = Blunder)

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

August 4, 2005

Project Report
City of Edmonds

Contract #2300-H

Report Presented to:

City of Edmonds
121 5th Avenue North
Edmonds, WA 98020
Point of Contact: Steve Bullock
Phone: (425) 771-0220
Fax: (425) 771-0221

1.Project Overview

Field Crew:

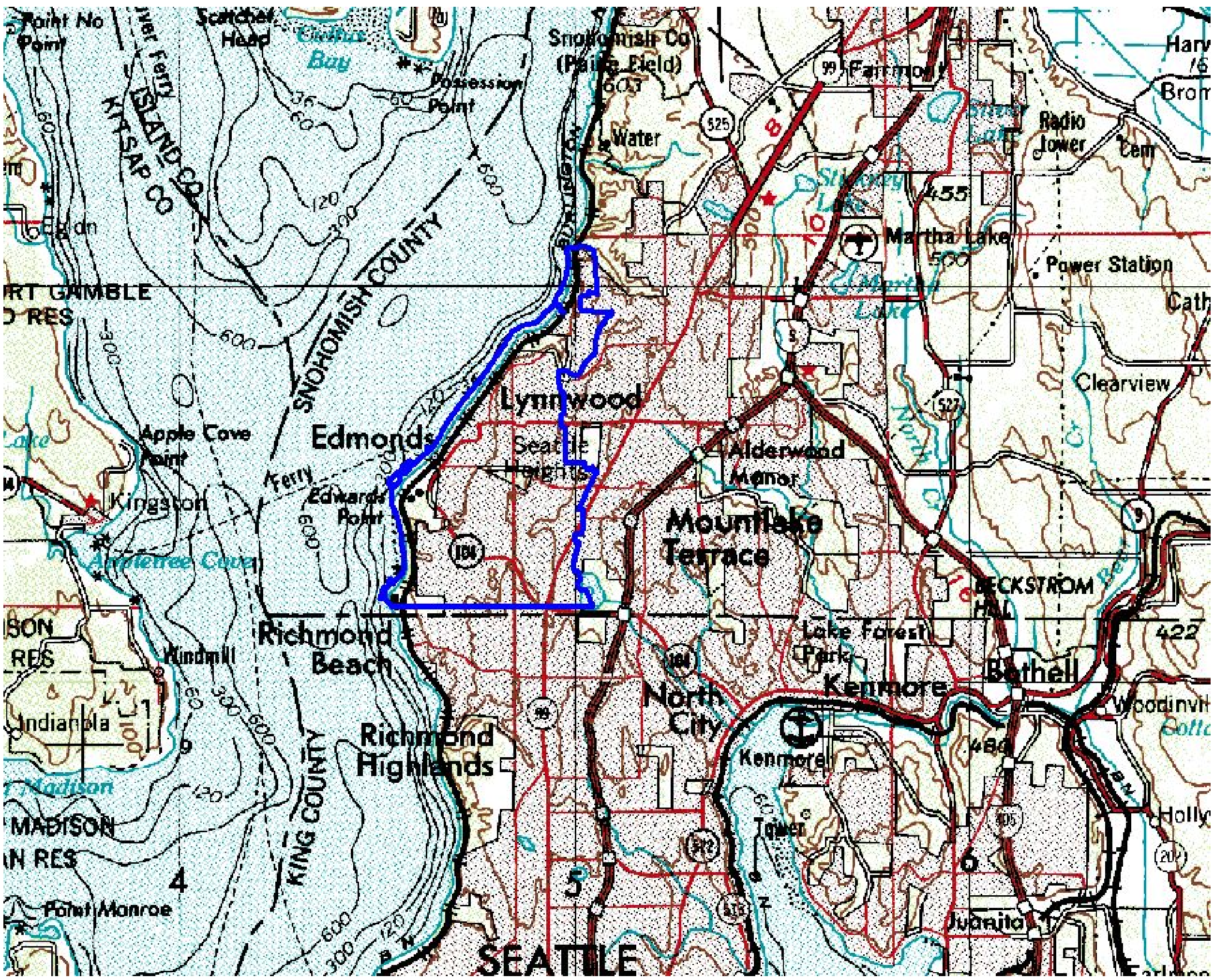
The Terrapoint field crew consisted of Todd Mitchell, field project manager and Barry Kaser, LIDAR operator. The Aries Aviation aircraft crew consisted of Andre Bourque, pilot and Bob Passon, flight engineer.

Post Processing Crew:

Barry Kaser completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Brian Herring and Joe Sackett.

Size of Project:

The project site covered approximately 11 square miles, as identified in the following image:



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Phone: (218) 364 – 4080
Fax: (218) 296– 0869

Location:

The project area is located in Snohomish County Washington .

Project Type:

The purpose of this project is to provide a high quality DEM of the site for City of Edmonds.

Approximate Duration of Project:

The field data collection took place on Feb. 27th, 2005. The control network and check point surveys were performed on March 2nd, 2005.

Calibration, vegetation removal and product generation took place from June 15th to July 15th, 2005.

Number of Flights:

One flight was required to cover the project area with 20 flight lines.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (HARN) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS

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monuments, including PIDs AE1858, SY5643 and temporary Terrapoint monument ARL1. Kinematic GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of all control coordinates is given in Table 1.

Table 1: Control and Base Coordinate							
NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
AE1858	48	16	23.39780	-121	39	34.13741	142.6619
SY5643	47	54	27.94094	-122	16	19.69519	156.947
ARL1	48	09	27.37695	-122	09	50.17267	16.6241

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

A Navajo twin-engine aircraft (C-GQVP) was used for this project. The aircraft was based out of Snohomish County Airport. The Navajo was typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Two Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
   +/- 15-20 centimeters on Hard Surfaces (roads and buildings)
   +/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
   +/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
   +/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
   2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 639 kinematic checkpoints collected along a roadway within the project site yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison	
Average dz	0.057
Minimum dz	-0.150
Maximum dz	0.269
Average magnitude	0.075
Root mean square	0.100
Std deviation	0.086

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

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Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAR data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

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There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

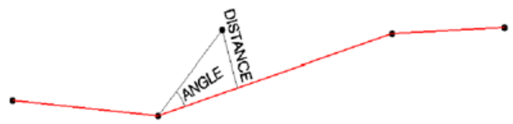

Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

Data delivered in format:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)

Bare Earth Point Data (DTM)

Data delivered in two formats:

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- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code (G = Ground, V = Vegetation/Non-Ground, S = Building/Structure, N = Vegetation or Building, B = Blunder)

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

April 15, 2005

Project Report

The Nature Conservancy – Port Susan and Fisher Slough

Contract #2305-H

Report Presented to:

The Nature Conservancy
217 Pine Street, Suite 1100
Seattle, Washington 98101
Point of Contact: Danelle Heatwole
Phone: (206) 343-4345 x393
Fax: (206) 343-5608
E-mail: dheatwole@tnc.org

1.Project Overview

Field Crew:

The Terrapoint field crew consisted of Shiva Shenoy, field project manager and Louis Hill, LIDAR operator. The Aries Aviation aircraft crew consisted of Rory Clayton, pilot and Bob Passon, flight engineer.

Post Processing Crew:

Shiva Shenoy completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Andrew Pace and Joe Sackett.

Size of Project:

The project site covered approximately 41 square miles, divided into two blocks:

- Fisher Slough - 18.5 square miles
- Port Susan – 22.5 square miles

Location:

The project area is located in Snohomish and Skagit County Washington (see image).

Project Type:

The purpose of this project is to provide a high quality DEM of the sites for The Nature Conservancy.

Approximate Duration of Project:

The field data collection took place from March 3rd to 5th, 2005. The control network and check point surveys were performed on March 4th, 2005.

Calibration, vegetation removal and product generation took place from March 15th to April 15th, 2005.

Number of Flights:

Two flights were required to cover the project areas. Twenty-one flight lines were required for Fisher Slough, and twenty-four for Port Susan.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (1991) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS monument PID TR2547. Kinematic GPS check points acquired as discrete x, y, z points were collected as part of the ground truthing activities. In addition to the above NGS monuments, Terrapoint also established 1 temporary first order control points for the survey project (230501). A summary of all control coordinates is given in Table 1.

Table 1: Control and Base Coordinate							
NAME	**Latitude**			**Longitude**			**Ellipsoidal Elevations (meters)**
TR2547	48	09	42.67994	-122	10	12.44883	17.4394
230501	48	20	13.68034	-122	19	52.98203	-19.8744

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

A Navajo twin-engine aircraft (C-FVZM) was used for this project. The aircraft was based out of Arlington Municipal Airport. The Navajo was typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Two Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:

+/- 15-20 centimeters on Hard Surfaces (roads and buildings)
+/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
+/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
+/- 20 – 60 centimeters on all but extremely hilly terrain.

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

For Fisher Slough, comparison of LIDAR data with 2004 kinematic checkpoints yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison – Fisher Slough	
Average dz	-0.061
Minimum dz	-0.204
Maximum dz	0.101
Average magnitude	0.067
Root mean square	0.076
Std deviation	0.045

For Port Susan, comparison of LIDAR data with 449 kinematic checkpoints yielded the results given in Table 3 (values in meters).

Table 3: Kinematic Point Comparison – Port Susan	
Average dz	-0.071
Minimum dz	-0.201
Maximum dz	0.100
Average magnitude	0.078
Root mean square	0.086
Std deviation	0.047

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Fax: (218) 296– 0869

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the lidar data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system. The average agreement between overlapping flight lines for each mission is given in Table 4 below.

Table 4: Overlapping Flight Line Differences

Day of Year	# of Overlapping Line Pairs	Average Difference (ft)	Average Standard Dev. (ft)
3/3/2005	50	0.077	0.098
3/5/2005	6	0.101	0.137

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

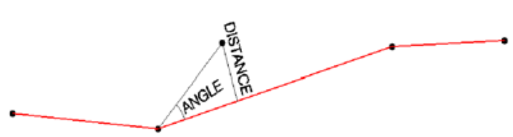

Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

6. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

7. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

Data delivered in format:

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Data delivered in two formats:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity

- Classification Code

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

July 29, 2005

Project Report
City of Marysville

Contract #2298-H

Report Presented to:

City of Marysville
80 Columbia Avenue
Marysville, WA 98270
Point of Contact: David Doop
Phone: (360) 363-8245
Fax: (360) 363-5099

1.Project Overview

Field Crew:

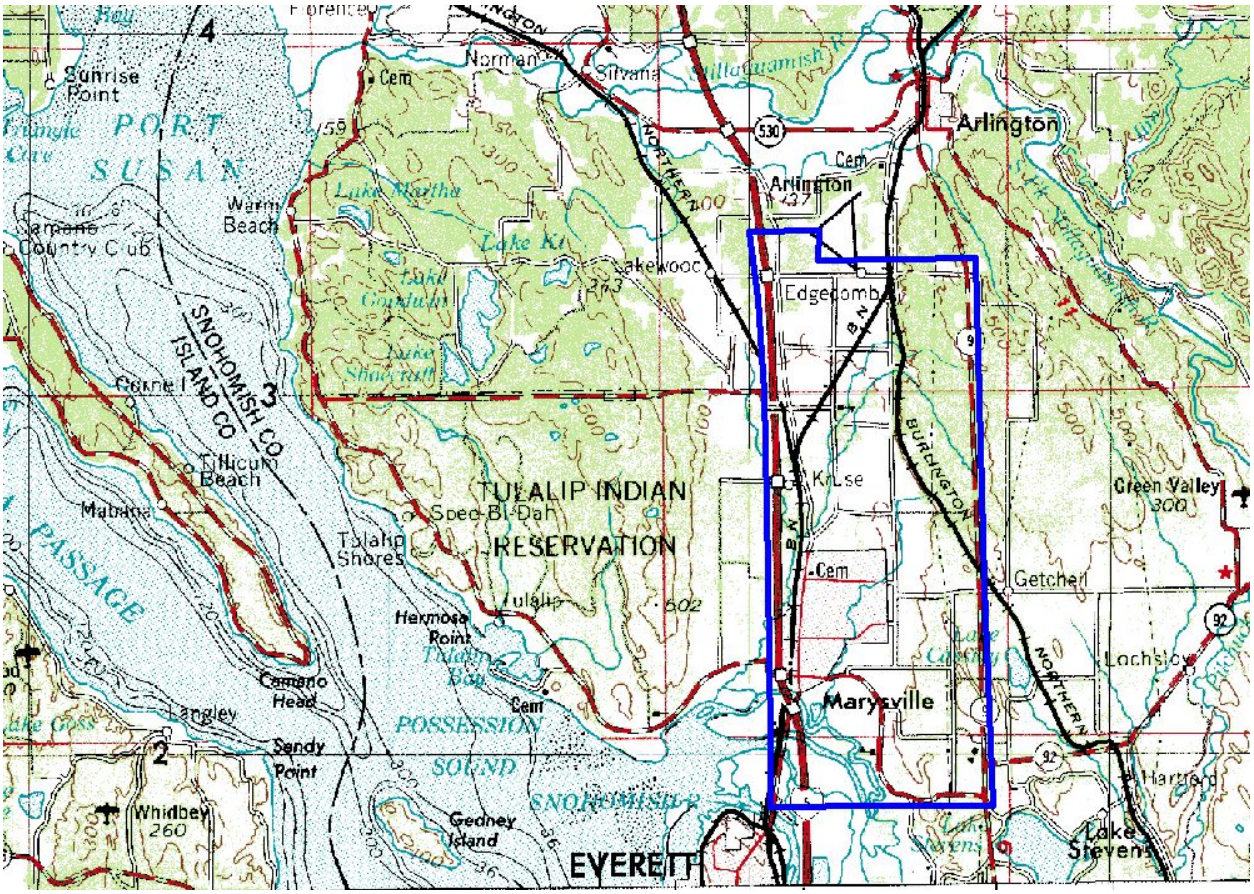
The Terrapoint field crew consisted of Todd Mitchell, field project manager and Shiva Shenoy, LIDAR operator. The Aries Aviation aircraft crew consisted of Andre Bourque, pilot and Bob Passon, flight engineer.

Post Processing Crew:

Todd Mitchell completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Brian Herring and Joe Sackett.

Size of Project:

The project site covered approximately 34 square miles, as identified in the following image:



Location:

The project area is located in Snohomish County Washington .

25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

Project Type:

The purpose of this project is to provide a high quality DEM of the site for City of Marysville.

Approximate Duration of Project:

The field data collection took place on Feb. 24th, 2005. The control network and check point surveys were performed on Feb. 28th, 2005.

Calibration, vegetation removal and product generation took place from May 15th to June 15th, 2005.

Number of Flights:

One flight was required to cover the project area with 22 flight lines.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (1998) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS monuments, including PID AE1858 and temporary Terrapoint monument ARL1. Kinematic GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of all control coordinates is given in Table 1.

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The Woodlands, TX 77380
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Table 1: Control and Base Coordinate							
NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
AE1858	48	16	23.39780	-121	39	34.13741	142.6619
ARL1	48	09	27.37695	-122	09	50.17267	16.6241

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

A Navajo twin-engine aircraft (C-GQVP) was used for this project. The aircraft was based out of Arlington Municipal Airport. The Navajo was typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Two Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
   +/- 15-20 centimeters on Hard Surfaces (roads and buildings)

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+/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
+/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
+/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 1101 kinematic checkpoints collected along two roadways within the project site yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison	
Average dz	-0.021
Minimum dz	-0.200
Maximum dz	0.160
Average magnitude	0.050
Root mean square	0.063
Std deviation	0.059

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

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The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAR data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

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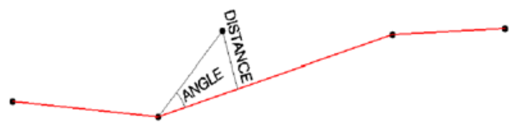

Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

Data delivered in format:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)

Bare Earth Point Data (DTM)

Data delivered in two formats:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

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The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code (G = Ground, V = Vegetation/Non-Ground, S = Building/Structure, N = Vegetation or Building, B = Blunder)

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

October 12, 2005

Project Report
City of MountLake Terrace

Contract #2303-H

terrapoint

Report Presented to:

City of Mountlake Terrace
23204 58th Avenue West
Mountlake Terrace, WA 98043-4629
Point of Contact: Shane Hope
Phone: (425) 744-6281
Fax: (425) 778-6421

1.Project Overview

Field Crew:

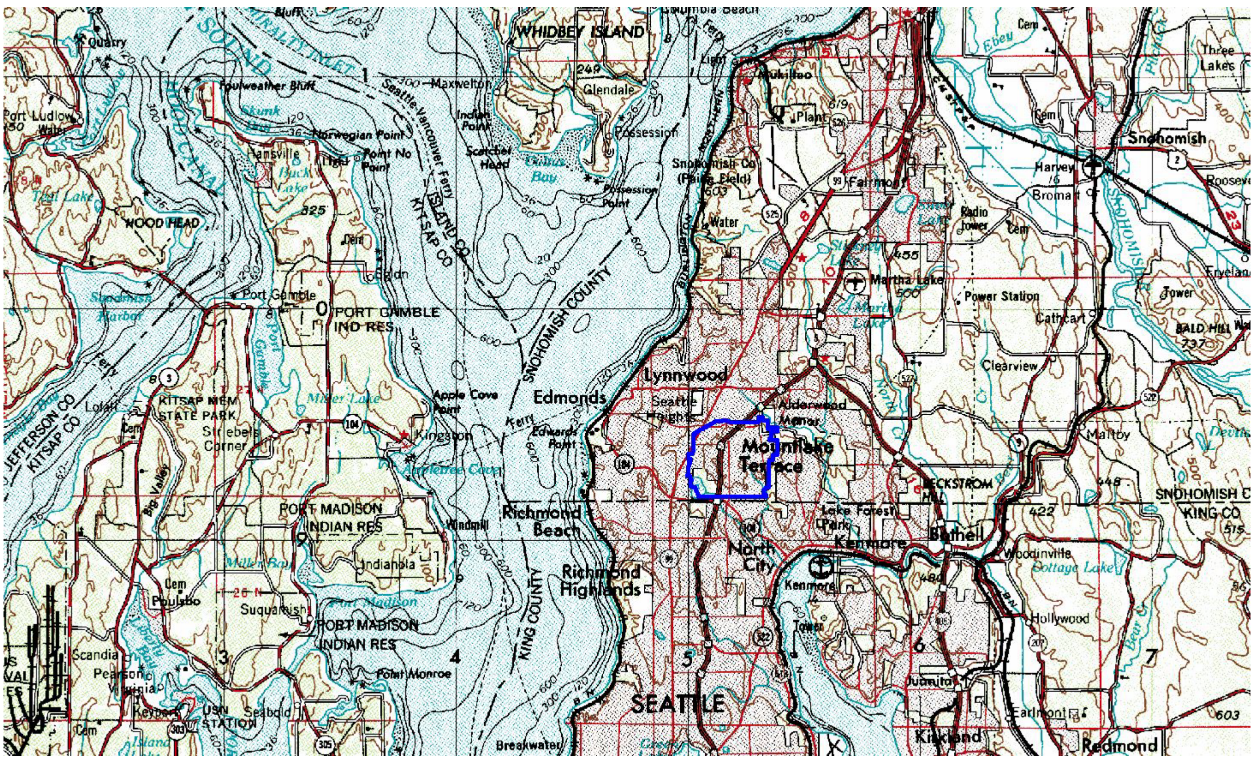
The Terrapoint field crew consisted of Todd Mitchell, field project manager and Barry Kaser, LIDAR operator. The Aries Aviation aircraft crew consisted of Andre Bourque, pilot and Bob Passon, flight engineer.

Post Processing Crew:

Barry Kaser completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Brian Herring and Joe Sackett.

Size of Project:

The project site covered approximately 4 square miles, as identified in the following image:



Location:

The project area is located in Snohomish County Washington .

Project Type:

The purpose of this project is to provide a high quality DEM of the site for City of Mountlake Terrace.

Approximate Duration of Project:

The field data collection took place on Feb. 27th, 2005. The control network and check point surveys were performed on March 2nd, 2005.

Calibration, vegetation removal and product generation took place from July 15th to September 15th, 2005.

Number of Flights:

One flight was required to cover the project area with 20 flight lines.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (HARN) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS monuments, including PIDs AE1858, SY5643 and temporary Terrapoint monument ARL1. Kinematic GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of all control coordinates is given in Table 1.

Table 1: Control and Base Coordinate							
NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
AE1858	48	16	23.39780	-121	39	34.13741	142.6619
SY5643	47	54	27.94094	-122	16	19.69519	156.947
ARL1	48	09	27.37695	-122	09	50.17267	16.6241

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

A Navajo twin-engine aircraft (C-GQVP) was used for this project. The aircraft was based out of Snohomish County Airport. The Navajo was typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Two Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
   +/- 15-20 centimeters on Hard Surfaces (roads and buildings)

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+/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
+/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
+/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 639 kinematic checkpoints collected along a roadway within the project site yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison	
Average dz	0.057
Minimum dz	-0.150
Maximum dz	0.269
Average magnitude	0.075
Root mean square	0.100
Std deviation	0.086

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAR data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

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The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

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The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

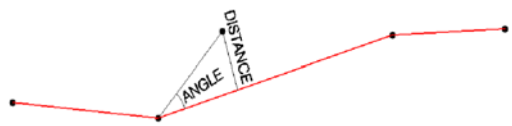

Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

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This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

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Data delivered in format:

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Bare Earth Point Data (DTM)

Data delivered in two formats:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code (G = Ground, V = Vegetation/Non-Ground, S = Building/Structure, N = Vegetation or Building, B = Blunder)

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

August 19, 2005

Project Report
City of Mukilteo

Contract #2301-H

Report Presented to:

City of Mukilteo
4480 Chennault Beach Road
Mukilteo, WA 98275
Point of Contact: Heather McCartney
Phone: (425) 355 – 4141 x 226
Fax: (425) 347 - 4544

1.Project Overview

Field Crew:

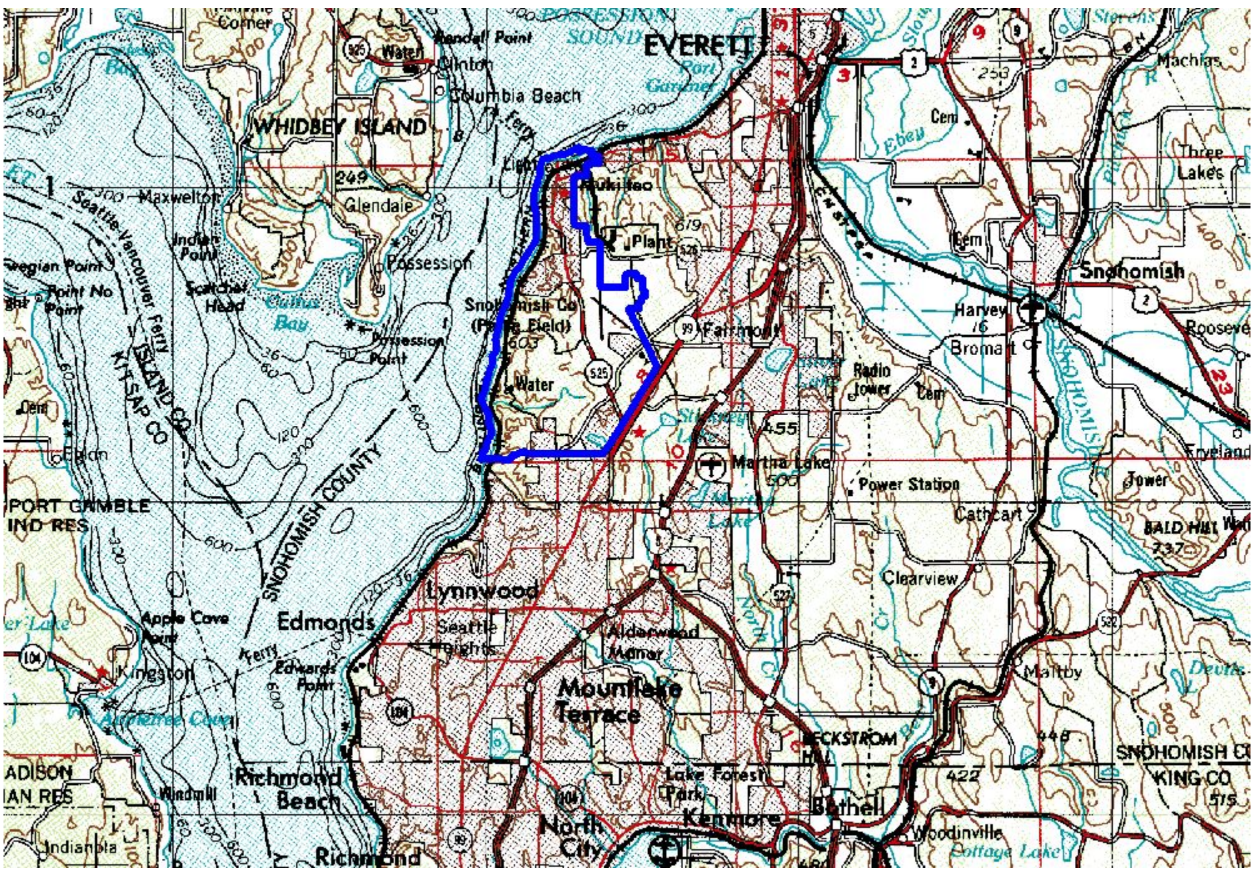
The Terrapoint field crew consisted of Todd Mitchell, field project manager and Barry Kaser, LIDAR operator. The Aries Aviation aircraft crew consisted of Andre Bourque, pilot and Bob Passon, flight engineer.

Post Processing Crew:

Barry Kaser completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Brian Herring and Joe Sackett.

Size of Project:

The project site covered approximately 16 square miles, as identified in the following image:



Location:

The project area is located in Snohomish County Washington .

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Project Type:

The purpose of this project is to provide a high quality DEM of the site for City of Mukilteo.

Approximate Duration of Project:

The field data collection took place on Feb. 27th, 2005. The control network and check point surveys were performed on March 2nd, 2005.

Calibration, vegetation removal and product generation took place from June 15th to July 15th, 2005.

Number of Flights:

One flight was required to cover the project area with 20 flight lines.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (HARN) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
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Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS monuments, including PIDs AE1858, SY5643 and temporary Terrapoint monument ARL1. Kinematic GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of all control coordinates is given in Table 1.

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Table 1: Control and Base Coordinate							
NAME		**Latitude**			**Longitude**		**Ellipsoidal Elevations (meters)**
AE1858	48	16	23.39780	-121	39	34.13741	142.6619
SY5643	47	54	27.94094	-122	16	19.69519	156.947
ARL1	48	09	27.37695	-122	09	50.17267	16.6241

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

A Navajo twin-engine aircraft (C-GQVP) was used for this project. The aircraft was based out of Snohomish County Airport. The Navajo was typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

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Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
   +/- 15-20 centimeters on Hard Surfaces (roads and buildings)

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+/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
+/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
   +/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
   2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

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Average magnitude	0.075
Root mean square	0.100
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5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

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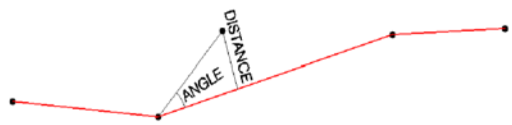

Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

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All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code (G = Ground, V = Vegetation/Non-Ground, S = Building/Structure, N = Vegetation or Building, B = Blunder)

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

June 5, 2005

Project Report

Nooksack South Fork – Lummi Indian Nation

Contract #2291-H

Report Presented to:

Lummi Indian Nation
Natural Resources Department
2616 Kwina Road
Bellingham, WA 98226
Point of Contact: Ann Stark
Phone: (360) 384-2340
Fax: (360) 384-4737

1.Project Overview

Field Crew:

The Terrapoint field crew consisted of Todd Mitchell, field project manager and Andrew Pace, LIDAR operator. The Aries Aviation aircraft crew consisted of Rory Clayton, pilot and Bob Passon, flight engineer.

Post Processing Crew:

Todd Mitchell completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, and Joe Sackett.

Size of Project:

The project site covered approximately 35 square miles, in a corridor along the south fork of the Nooksack River.

Location:

The project area is located in Whatcom County Washington .

Project Type:

The purpose of this project is to provide a high quality DEM of the site for the Lummi Indian Nation.

Approximate Duration of Project:

The field data collection took place on April 20th, 2005. The control network and check point surveys were performed on April 16th, 2005.

Calibration, vegetation removal and product generation took place from April 25th to May 30th, 2005.

Number of Flights:

One flight was required to cover the project area with 35 flight lines.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (1998) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS monument PID AI0441 and WSDOT monuments 3409 and 3412. Kinematic GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of all control coordinates is given in Table 1.

Table 1: Control and Base Coordinate

NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
AI0441	48	47	00.05659	-122	32	11.19213	28.489
3409	48	47	20.63156	-122	11	25.83857	54.600
3412	48	47	20.83687	-122	11	55.59815	54.497

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

A Navajo twin-engine aircraft (C-FVZM) was used for this project. The aircraft was based out of Arlington Municipal Airport. The Navajo was typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Two Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
   +/- 15-20 centimeters on Hard Surfaces (roads and buildings)
   +/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
   +/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
   +/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
   2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 143 kinematic checkpoints collected along a roadway just outside the project site yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison	
Average dz	-0.046
Minimum dz	-0.026
Maximum dz	0.093
Average magnitude	0.047
Root mean square	0.053
Std deviation	0.026

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAR data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

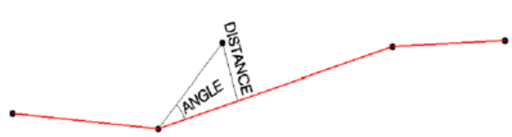


Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

Data delivered in format:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)

Bare Earth Point Data (DTM)

Data delivered in two formats:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

May 5, 2005

Project Report
Nooksack North Fork – Nooksack Natural Resources

Contract #2309-H

Terrapoint

Report Presented to:

Nooksack Natural Resources
5016 Deming Road
Deming, WA 98244
Point of Contact: Tim Hyatt
Phone: (360) 592 – 2632 x 3282
Fax: (360) 592 – 5753

1.Project Overview

Field Crew:

The Terrapoint field crew consisted of John Anderson, field project manager and Louis Hill, LIDAR operator. The Aries Aviation aircraft crew consisted of Rory Clayton, pilot and Bob Passon, flight engineer.

Post Processing Crew:

John Anderson completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Andrew Pace and Joe Sackett.

Size of Project:

The project site covered approximately 21.5 square miles, in a corridor along the Nooksack River.

Location:

The project area is located in Whatcom County Washington .

Project Type:

The purpose of this project is to provide a high quality DEM of the site for Nooksack Natural Resources.

Approximate Duration of Project:

The field data collection took place on March 23rd, 2005. The control network and check point surveys were performed on April 11th, 2005.

Calibration, vegetation removal and product generation took place from April 15th to April 30th, 2005.

Number of Flights:

One flight was required to cover the project area with 41 flight lines.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (1998) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS monument PID AI0441 and WSDOT monuments 3409 and 3412. Kinematic GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of all control coordinates is given in Table 1.

Table 1: Control and Base Coordinate

NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
AI0441	48	47	00.05659	-122	32	11.19213	28.489
3409	48	47	20.63156	-122	11	25.83857	54.600
3412	48	47	20.83687	-122	11	55.59815	54.497

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

A Navajo twin-engine aircraft (C-FVZM) was used for this project. The aircraft was based out of Bellingham International Airport. The Navajo was typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Two Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
   +/- 15-20 centimeters on Hard Surfaces (roads and buildings)
   +/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
   +/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
   +/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
   2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 460 kinematic checkpoints collected along two roadways within the project site yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison	
Average dz	-0.003
Minimum dz	-0.105
Maximum dz	0.068
Average magnitude	0.026
Root mean square	0.031
Std deviation	0.031

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAR data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

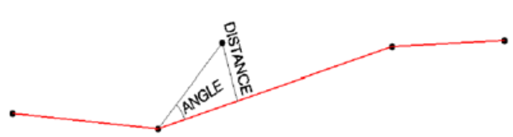


Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

Data delivered in format:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)

Bare Earth Point Data (DTM)

Data delivered in two formats:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

July 27, 2005

Project Report

Sauk River North

Contract #2293-H & 2296-H

Terrapoint

Report Presented to:

Washington Dept. of Natural Resources
Resource Mapping Section
1111 Washington Street SE
Olympia, WA 98504-7032
Point of Contact: Terry Curtis
Phone: (360) 902-1210
Fax: (360) 902-1778

Skagit County GIS
700 South 2nd Street. Room 202
Mount Vernon, WA. 98273
Point of Contact: Joshua Greenberg
Phone: (360) 336-9368 ext.16
Fax: (360) 336-9466

1.Project Overview

Field Crew:

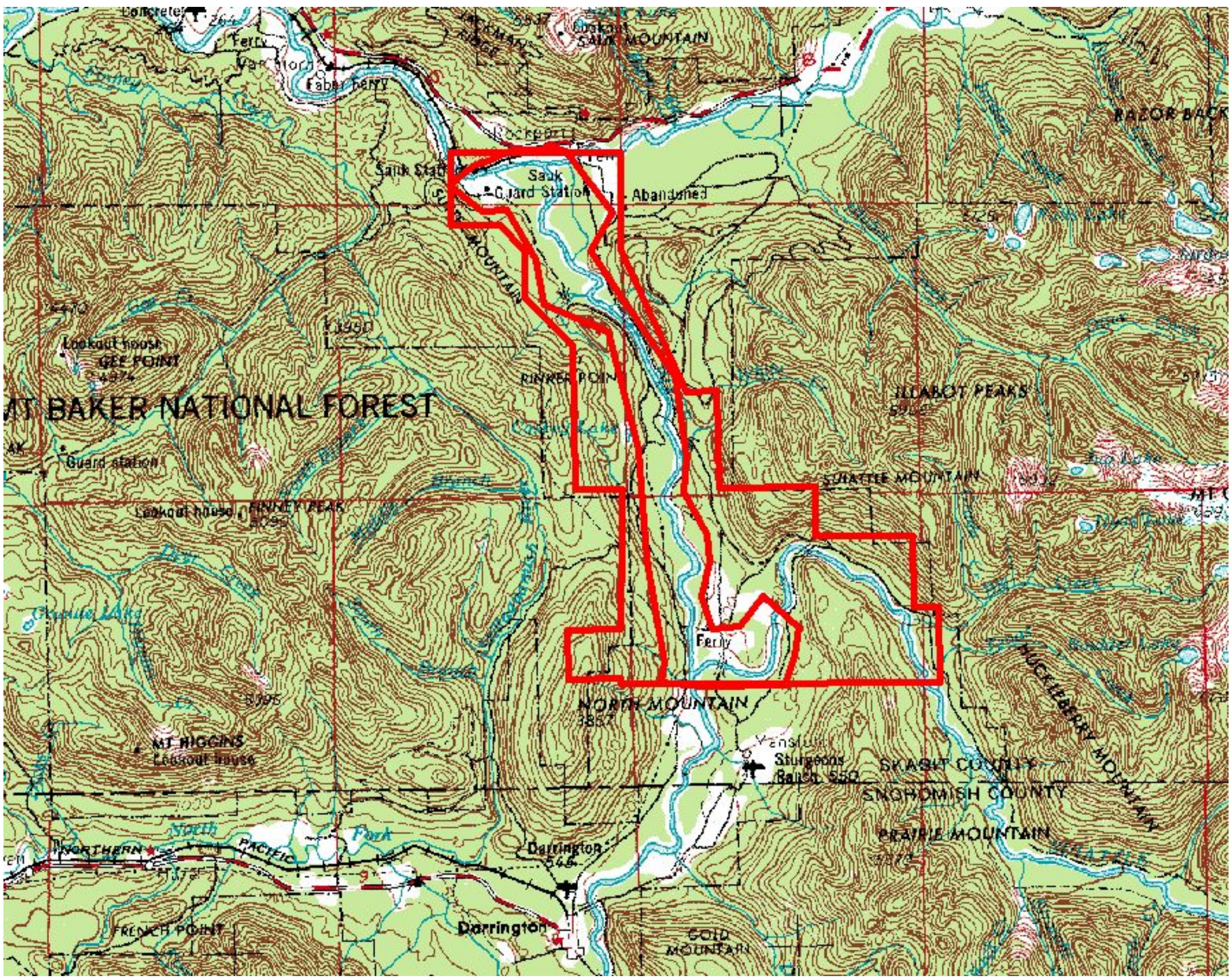
The Terrapoint field crew consisted of Todd Mitchell, field project manager and Andy Pace, LIDAR operator. The Aries Aviation aircraft crew consisted of Andre Bourque and Rory Clayton, pilots and Bob Passon, flight engineer.

Post Processing Crew:

Todd Mitchell completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Brian Herring and Joe Sackett.

Size of Project:

The project site covered approximately 42 square miles, as identified in the following image:



25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

Location:

The project area is located in Skagit County Washington .

Project Type:

The purpose of this project is to provide a high quality DEM of the site for DNR and Skagit County.

Approximate Duration of Project:

The field data collection took place from April 10th to April 19th, 2005. The control network and check point surveys were performed on April 7th, 2005.

Calibration, vegetation removal and product generation took place from June 15th to July 15th, 2005.

Number of Flights:

Three flights were required to cover the project area with 46 flight lines.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (1998) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS

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monuments, including PID AE1858 and temporary Terrapoint monuments ARL1 and 229401. Kinematic GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of control coordinates is given in Table 1.

Table 1: Control and Base Coordinate							
NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
AE1858	48	16	23.39780	-121	39	34.13741	142.6619
ARL1	48	09	27.37695	-122	09	50.17267	16.6241
229401	48	31	33.87820	-121	25	36.99562	77.5670

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

Two Navajo twin-engine aircraft (C-GQVP and C-FVZM) were used for this project. The aircraft were based out of Arlington Municipal Airport. The Navajo were typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

Two systems were used in parallel to accomplish data collection:

1. Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots (C-FVZM). The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.
2. Terrapoint's 20 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3000 ft AGL at 140 knots (C-GQVP). The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 917 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Three Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

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4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
   +/- 15-20 centimeters on Hard Surfaces (roads and buildings)
   +/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
   +/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
   +/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
   2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 296 kinematic checkpoints collected along two roadways within the project site yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison	
Average dz	-0.036
Minimum dz	-0.159
Maximum dz	0.078
Average magnitude	0.045
Root mean square	0.055
Std deviation	0.041

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

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The Woodlands, TX 77380
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Fax: (218) 296– 0869

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAR data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

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The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

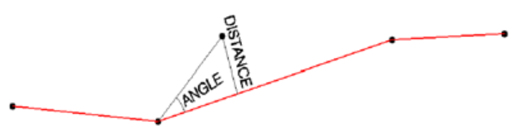


Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

Data delivered in format:

25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)

Bare Earth Point Data (DTM)

Data delivered in two formats:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code (G = Ground, V = Vegetation/Non-Ground, S = Building/Structure, N = Vegetation or Building, B = Blunder)

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

July 28, 2005

Project Report
Sauk-Suiattle Indian Tribe

Contract #2294-H

Report Presented to:

Sauk-Suiattle Indian Tribe
5318 Chief Brown Lane
Darrington, WA 98241
Phone: (360) 436-0738
Fax: (360) 436-1092

1. Project Overview

Field Crew:

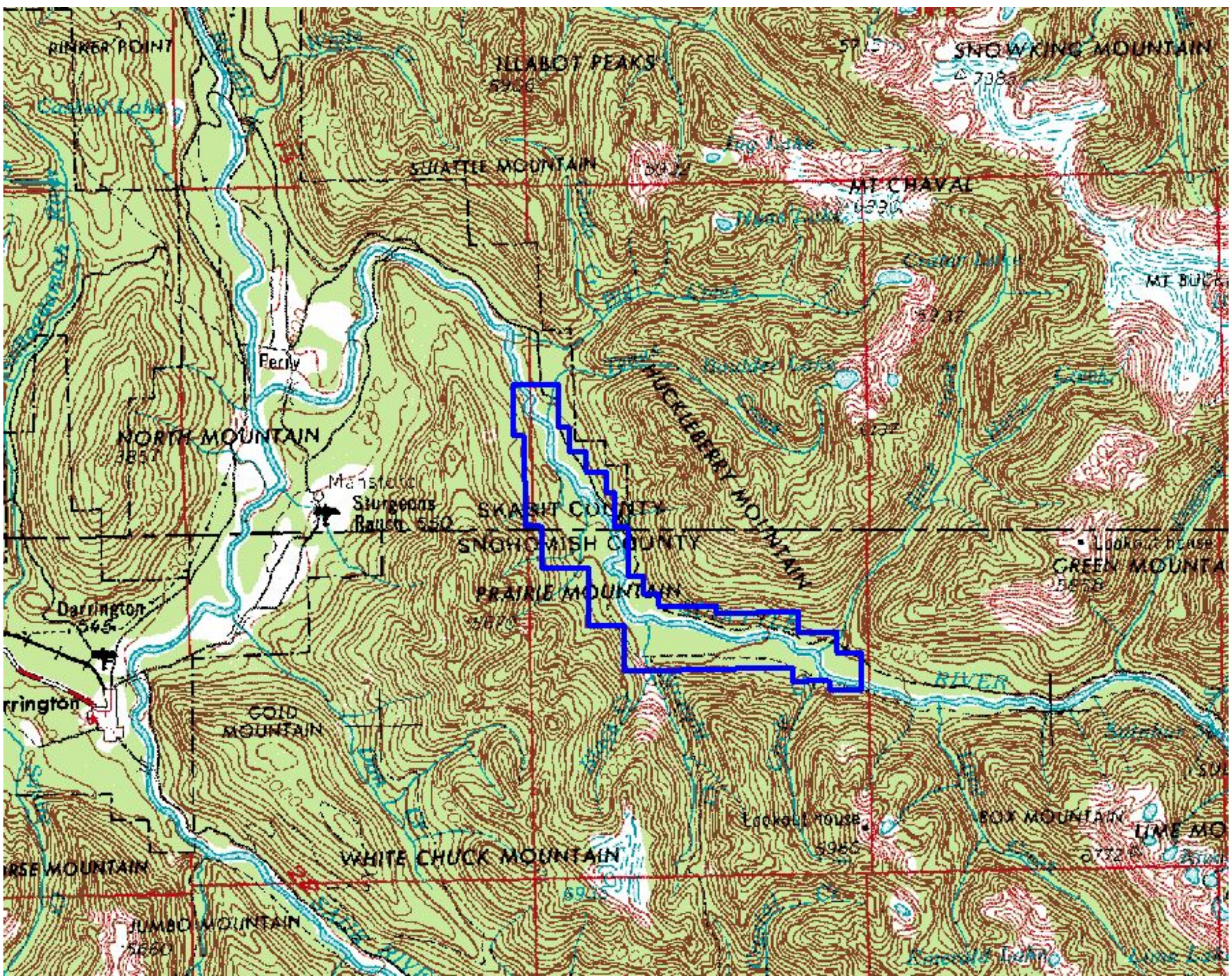
The Terrapoint field crew consisted of Todd Mitchell, field project manager and Andy Pace, LIDAR operator. The Aries Aviation aircraft crew consisted of Andre Bourque and Rory Clayton, pilots and Bob Passon, flight engineer.

Post Processing Crew:

Todd Mitchell completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Brian Herring and Joe Sackett.

Size of Project:

The project site covered approximately 8 square miles, as identified in the following image:



25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

Location:

The project area is located in Skagit and Snohomish Counties, Washington .

Project Type:

The purpose of this project is to provide a high quality DEM of the site for the Sauk-Suiattle Tribe.

Approximate Duration of Project:

The field data collection took place from April 10th to April 19th, 2005. The control network and check point surveys were performed on April 7th, 2005.

Calibration, vegetation removal and product generation took place from June 15th to July 15th, 2005.

Number of Flights:

Two flights were required to cover the project area with 22 flight lines.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (1998) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS

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monuments, including PID AE1858 and temporary Terrapoint monuments ARL1 and 229401. Kinematic GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of control coordinates is given in Table 1.

Table 1: Control and Base Coordinate								
NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
AE1858	48	16	23.39780	-121	39	34.13741	142.6619
ARL1	48	09	27.37695	-122	09	50.17267	16.6241
229401	48	31	33.87820	-121	25	36.99562	77.5670

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

Two Navajo twin-engine aircraft (C-GQVP and C-FVZM) were used for this project. The aircraft were based out of Arlington Municipal Airport. The Navajo were typically flying at an altitude of 3500 or 3000 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

Two systems were used in parallel to accomplish data collection:

1. Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots (C-FVZM). The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.
2. Terrapoint's 20 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3000 ft AGL at 140 knots (C-GQVP). The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 917 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Three Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

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4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
   +/- 15-20 centimeters on Hard Surfaces (roads and buildings)
   +/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
   +/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
   +/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
   2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 296 kinematic checkpoints collected along two roadways within the project site yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison	
Average dz	-0.036
Minimum dz	-0.159
Maximum dz	0.078
Average magnitude	0.045
Root mean square	0.055
Std deviation	0.041

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

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The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAR data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

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The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

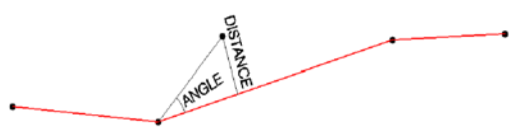


Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

Data delivered in format:

25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
Fax: (218) 296– 0869

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)

Bare Earth Point Data (DTM)

Data delivered in two formats:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code (G = Ground, V = Vegetation/Non-Ground, S = Building/Structure, N = Vegetation or Building, B = Blunder)

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

June 20, 2005

Project Report
Skagit River System Cooperative

Contract #2282-H

terrapoint

Report Presented to:

Skagit River System Cooperative
11426 Moorage Way, PO Box 368
LaConner, WA 98257
Phone: (360) 466-7308
Fax: (360) 466-4047

1.Project Overview

Field Crew:

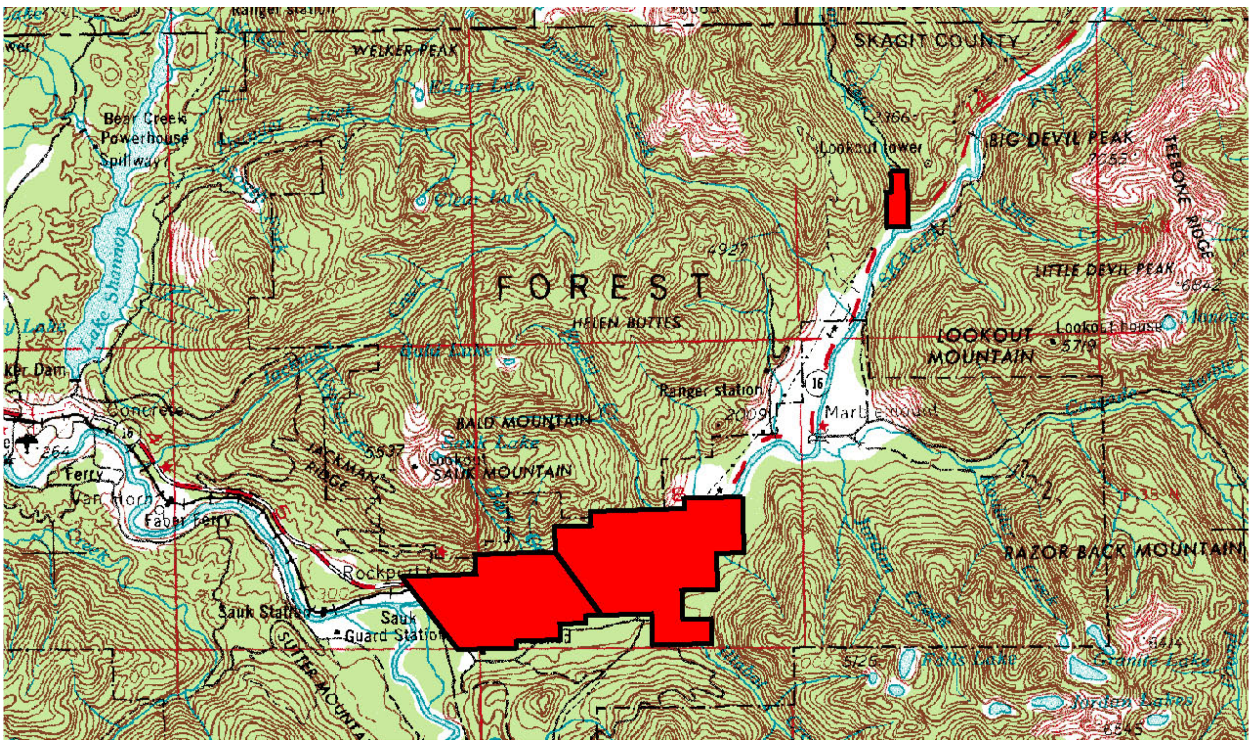
The Terrapoint field crew consisted of John Anderson, field project manager and Andy Pace, LIDAR operator. The Aries Aviation aircraft crew consisted of Rory Clayton, pilot and Bob Passon, flight engineer.

Post Processing Crew:

John Anderson completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Brian Herring and Joe Sackett.

Size of Project:

The project site covered approximately13 square miles, broken into two project blocks as identified in the following image:



Location:

The project area is located in Skagit County Washington .

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Project Type:

The purpose of this project is to provide a high quality DEM of the site for Skagit River System Cooperative.

Approximate Duration of Project:

The field data collection took place on April 8th and 10th, 2005. The control network and check point surveys were performed on April 7th, 2005.

Calibration, vegetation removal and product generation took place from May 15th to June 15th, 2005.

Number of Flights:

Two flights were required to cover the project area with 21 flight lines (south block) and 3 flight lines (north block).

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (1998) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS monuments, including PID AE1858 and temporary Terrapoint monuments ARL1 and 229401. Kinematic GPS check points were acquired as discrete x, y, z

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points were collected as part of the ground truthing activities. A summary of all control coordinates is given in Table 1.

Table 1: Control and Base Coordinate							
NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
AE1858	48	16	23.39780	-121	39	34.13741	142.6619
ARL1	48	09	27.37695	-122	09	50.17267	16.6241
229401	48	31	33.87820	-121	25	36.99561	77.5653

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

A Navajo twin-engine aircraft (C-FVZM) was used for this project. The aircraft was based out of Arlington Municipal Airport. The Navajo was typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Two Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

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1. Absolute Vertical Accuracy:
   +/- 15-20 centimeters on Hard Surfaces (roads and buildings)
   +/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
   +/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
   +/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
   2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 639 kinematic checkpoints collected along four roadways within the project site (3 in the south block, 1 in the north) yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison	
Average dz	-0.029
Minimum dz	-0.172
Maximum dz	0.091
Average magnitude	0.046
Root mean square	0.057
Std deviation	0.049

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

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Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAR data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

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There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

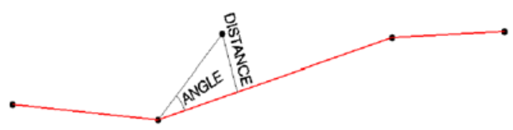

Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

Data delivered in format:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)

Bare Earth Point Data (DTM)

Data delivered in two formats:

25216 Grogans Park Drive
The Woodlands, TX 77380
Phone: (218) 364 – 4080
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- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code (G = Ground, V = Vegetation/Non-Ground, S = Building/Structure, N = Vegetation or Building, B = Blunder)

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

25216 Grogans Park Drive
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April 28, 2005

Project Report

Sustainable Environments LLC – Skagit Environmental Bank

Contract #2322-H

Terrapoint

Report Presented to:

Sustainable Environments, LLC
9 Teaberry Lane
Tiburon CA 94920
Point of Contact: Jerome Ryan
Phone: (415) 434 – 3734

1.Project Overview

Field Crew:

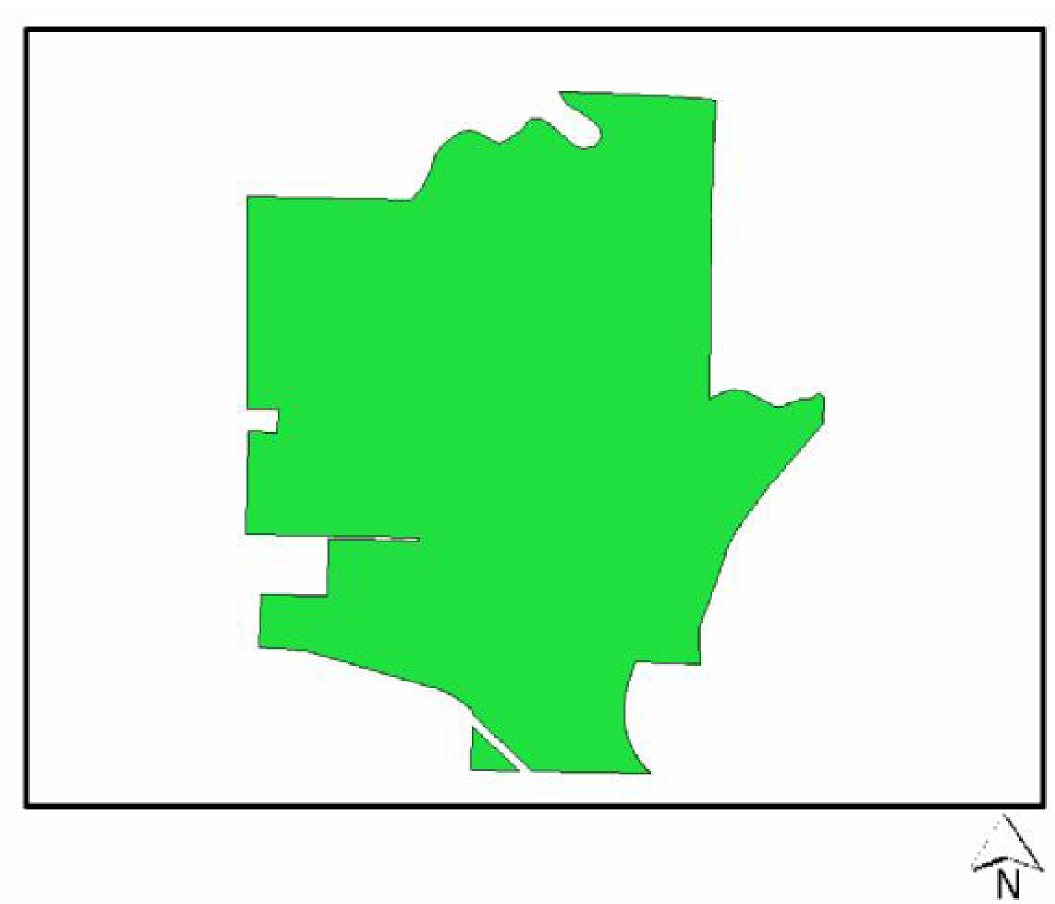
The Terrapoint field crew consisted of John Anderson, field project manager and Louis Hill, LIDAR operator. The Aries Aviation aircraft crew consisted of Rory Clayton, pilot and Bob Passon, flight engineer.

Post Processing Crew:

John Anderson completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Andrew Pace and Joe Sackett.

Size of Project:

The project site covered approximately 1.26 square miles, as shown in the following image.



Location:

The project area is located in Skagit County Washington .

Project Type:

The purpose of this project is to provide a high quality DEM and contours of the site for Sustainable Environments, LLC.

Approximate Duration of Project:

The field data collection took place on April 6th, 2005. The control network and check point surveys were performed from April 9th to 11th, 2005.

Calibration, vegetation removal and product generation took place from April 15th to April 25th, 2005.

Number of Flights:

One flight was required to cover the project area with 13 flight lines, six flight lines in a N-S direction, and seven flight lines in a E-W direction.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (1998) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS monument PID TR2547 and WSDOT monument WS1945. Kinematic and Static

GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of all control coordinates is given in Table 1.

Table 1: Control and Base Coordinate							
NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
TR2547	48	09	42.67994	-122	10	12.44883	17.4394
WS1945	48	25	48.28410	-122	15	52.35410	11.443

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

A Navajo twin-engine aircraft (C-FVZM) was used for this project. The aircraft was based out of Arlington Municipal Airport. The Navajo was typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Two Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
   +/- 10-15 centimeters on Hard Surfaces (roads and buildings)
   +/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
   +/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
   +/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy (as agreed with CUSTOMER):
   1 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, static and kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 10 static checkpoints yielded the results given in Table 2 (values in meters).

Table 2: Static Control Comparison

Pt ID	Easting	Northing	Elevation	Laser Elev.	dZ
2322gt01	554430.926	5364410.367	32.989	33.010	0.021
2322gt02	552428.431	5364995.029	16.153	16.050	-0.103
2322gt03	552818.780	5364674.742	23.032	22.990	-0.042
2322gt04	552887.327	5367376.170	37.290	37.330	0.040
2322gt06	555357.567	5366150.417	15.969	15.950	-0.019
2322gt07	554807.040	5366357.346	13.333	13.400	0.067
2322gt08	554389.799	5366738.601	12.043	12.100	0.057
2322gt09	553157.202	5367220.868	23.021	23.070	0.049
DH212	554407.742	5364965.546	37.257	37.500	0.243
WS1945	554404.085	5364364.745	33.698	33.660	-0.038

Average dz	0.028
Minimum dz	-0.103
Maximum dz	0.243
Average magnitude	0.068
Root mean square	0.092
Std deviation	0.093

A comparison of LIDAR data with 278 kinematic checkpoints yielded the results given in Table 3 (values in meters).

Table 3: Kinematic Point Comparison	
Average dz	-0.019
Minimum dz	-0.156
Maximum dz	0.123
Average magnitude	0.036
Root mean square	0.046
Std deviation	0.042

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAr data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

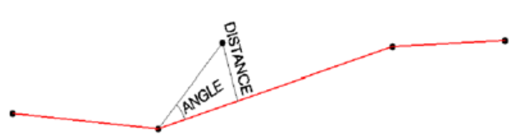


Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

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This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

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Full Feature or All Return Point Data (DEM)

Data delivered in format:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)

Bare Earth Point Data (DTM)

Data delivered in two formats:

- ArcInfo Grid File Format. Six foot grid spacing. File delivered by USGS quarter quad in gzipped Arcinfo Exchange Format (e00)
- ASCII xyz file format. Space delimited (.txt gzipped by USGS quarter quad)

All Return Text File (All Return)

All collected data delivered in ASCII text file format (space delimited) with the following columns

- GPS Week
- GPS Time (seconds)
- Easting (US feet)
- Northing (US feet)
- Elevation (Orthmetric, US feet)
- Total # of Returns in Pulse
- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code

Data is delivered by 1/25th of a USGS quarter quad in gzipped .txt files

One Foot Contour Map

Contour Map was delivered in two formats:

- Microstation V8 DGN File
- Arcview 3D Shape File

Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

August 22, 2005

Project Report
Snohomish County Floodplains LiDAR Survey

Contract #2295-H

Report Presented to:

David Evans and Associates, Inc. (DEA)
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1.Project Overview

Field Crew:

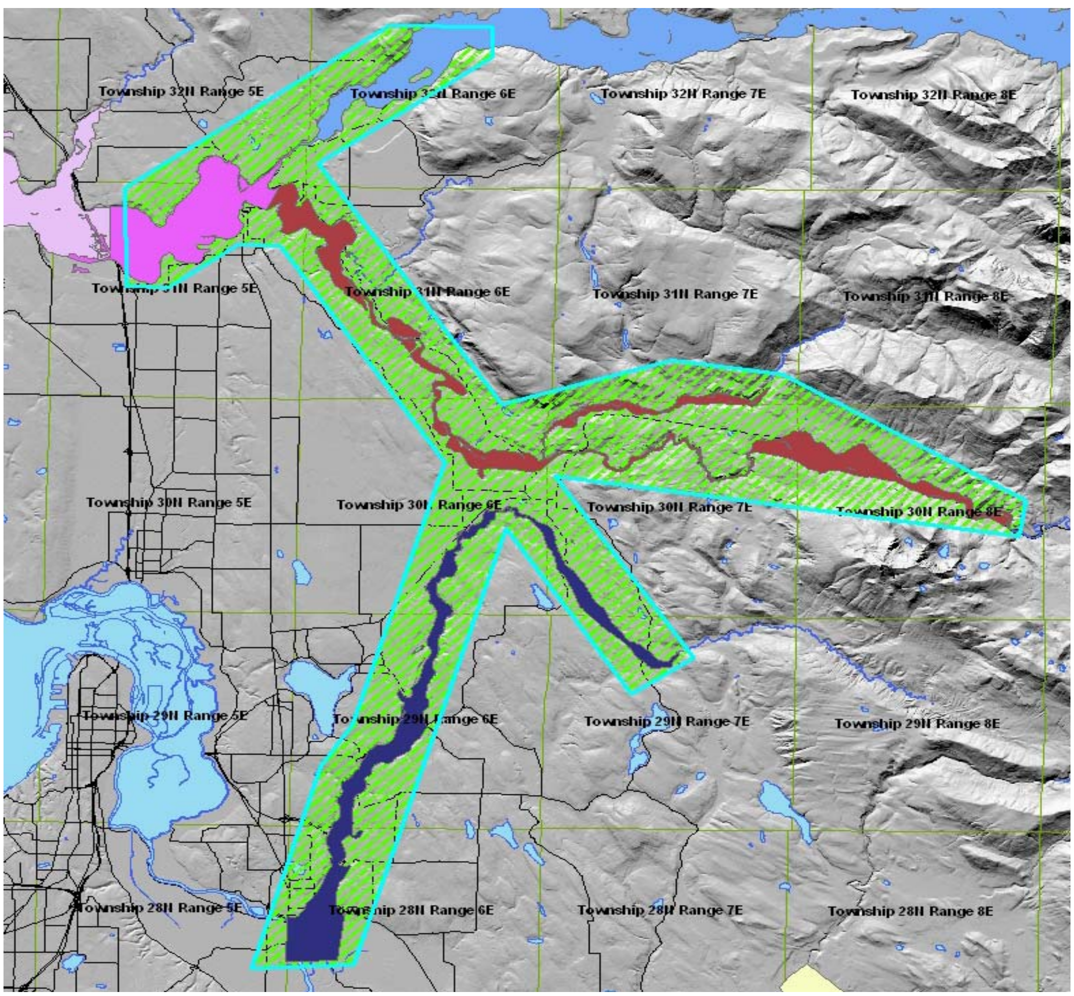
The Terrapoint field crew consisted of Todd Mitchell and Shiva Shenoy, field project managers and Barry Kaser, LIDAR operator. The Aries Aviation aircraft crew consisted of Andre Bourque and Rory Clayton, pilots and Bob Passon, flight engineer.

Post Processing Crew:

Todd Mitchell completed the processing of GPS data. Craig Glennie carried out data validation and calibration. Vegetation removal and final product generation were completed the Houston processing team: Peggy Cobb, Brian Herring and Joe Sackett.

Size of Project:

The project site covered approximately 118 square miles, as identified in the following image:



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Location:

The project area is located in Snohomish County Washington .

Project Type:

The purpose of this project is to provide a high quality DEM of the site for flood plain mapping.

Approximate Duration of Project:

The field data collection took place from Feb. 23rd to Feb. 26th, 2005. The control network and check point surveys were performed on Feb. 28th, 2005.

Calibration, vegetation removal and product generation took place from April 15th to July 15th, 2005.

Number of Flights:

Four flights were required to cover the project area with 72 flight lines.

Coordinate System(s) Used:

All horizontal coordinate data was collected and referenced to NAD83 (HPGN) and NAVD88 and delivered in US State Plane Zone Washington North (4601). GEOID03 for CONUS was applied to the vertical component of all deliverables.

Survey Measurement Units Used/Delivered:

All surveys were conducted and products delivered in US survey feet.

Processing Software Used:

The following software was used to reduce the GPS kinematic data, compute the 3-D laser points, classify and edit laser points, produce shaded relief images and transform the ellipsoidal heights to Orthometric:

- ArcView
- Flykin
- Microstation
- TerraScan
- TerraModeler
- TerraModel
- Terrapoint Proprietary LiDAR processing software

Capsule Review of Ground Control Survey(s) and Adjustment(s)

Terrapoint's field crew acquired and adjusted the ground control survey information. Terrapoint collected all of their LiDAR data referenced to NGS

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monuments, including PIDs AE1858, TR2547, TR2548 and TR0175 and temporary Terrapoint monument ARL1. Kinematic GPS check points were acquired as discrete x, y, z points were collected as part of the ground truthing activities. A summary of all control coordinates is given in Table 1.

Table 1: Control and Base Coordinate							
NAME	Latitude			Longitude			Ellipsoidal Elevations (meters)
AE1858	48	16	23.39780	-121	39	34.13741	142.6619
ARL1	48	09	27.37695	-122	09	50.17267	16.6241
TR2547	48	09	42.67994	-122	10	12.44883	17.4394
TR2548	48	10	13.17978	-122	09	15.95547	20.354
TR0175	48	08	01.52294	-122	09	18.59275	10.343

2. Health and Safety

Following Terrapoint's safety procedures, the field crew conducted a safety meeting upon arrival at the project site.

3. Equipment Used

Aircraft Type:

Two Navajo twin-engine aircraft (C-GQVP and C-FZVM) were used for this project. The aircraft was based out of Arlington Municipal Airport. The Navajo were typically flying at an altitude of 3500 feet AGL (above ground level) for the duration of the survey.

Sensors Used:

The Airborne LiDAR survey was conducted using Terrapoint's 40 kHz ALTMS (Airborne Laser Terrain Mapping System), flying at an optimum height of 3500 ft AGL at 140 knots. The system consists of a 36-degree full angle laser, a Trimble 4700 GPS receiver and a Honeywell H764 IMU unit. The nominal flight line spacing was 1070 feet, providing overlap of 50% between flight lines.

GPS Type(s):

Four Sokkia GSR2600 dual frequency GPS receivers were used to support the airborne operations on this project.

4. Accuracy

The following list itemizes the accuracy attainable over the project area, as a function of terrain type and vegetation cover. Note that the accuracy quoted is

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the accuracy of the attainable DEM, once it is processed and edited to this stage. All data accuracies quoted relate to post processed GPS/IMU/LiDAR solutions.

Accuracy is as follows, quoted at the 95% confidence level (2 sigma),

1. Absolute Vertical Accuracy:
   +/- 15-20 centimeters on Hard Surfaces (roads and buildings)
   +/- 15-25 centimeters on Soft/Vegetated Surfaces (flat to rolling terrain)
   +/- 25-40 centimeters on Soft/Vegetated Surfaces (hilly terrain)

2. Absolute Horizontal Accuracy:
   +/- 20 – 60 centimeters on all but extremely hilly terrain.

3. Contour Accuracy:
   2 ft Contour National Map Accuracy Standard (NMAS)

To verify that the accuracy criteria were being achieved, kinematic checkpoints were compared with a triangulated surface generated from the bald earth LiDAR points.

A comparison of LIDAR data with 858 kinematic checkpoints collected along five roadways within the project site yielded the results given in Table 2 (values in meters).

Table 2: Kinematic Point Comparison	
Average dz	-0.022
Minimum dz	-0.200
Maximum dz	0.157
Average magnitude	0.051
Root mean square	0.064
Std deviation	0.060

5. Quality Control

Quality control of the data was ongoing throughout the process. Following data acquisition, preliminary GPS processing was conducted in the field to ensure completeness and integrity.

The GPS and inertial data were processed in tandem to achieve the best positional result. Once the position and attitude of the aircraft were known at each epoch (1-second intervals), then these data were integrated with the laser

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ranges to provide a position for each data point on the ground. The data were then processed using the proprietary laser processing software suite to produce coordinates.

Each flight involved setting up two base stations to collect data. Utilizing two base stations ensures GPS data collection in the event that the main base station fails. For all flights the GPS data were of high quality. This minimized the absolute error for the aircraft position.

The primary quality control tool for the laser ranges is the percentage of returns that are received back at the laser after it has emitted a signal. The acceptable range for returns, typically between 90% and 95% was met for this project. Lower percentages are normal over water and other poor reflectivity surfaces.

Terrapoint also utilizes a proprietary software package that performs a fully automated analysis of the quality of the LIDAR data using overlapping flight lines. Our flight lines overlap 30 to 50% on either side and thus 60 to 100% of points can be checked for overlap consistency. The overlap analysis attempts to minimize the differences in overlap areas by fine-tuning the calibration parameters of the LIDAR system.

6. Point Generation

The points are generated as Terrascan binary Format using Terrapoint's proprietary Laser Postprocessor Software. This software combines the Raw Laser file and GPS/IMU information to generate a point cloud for each individual flight.

All the point cloud files encompassing the project area were then divided into quarter quad tiles. The referencing system of these tiles is based upon the project boundary minimum and maximums. This process is carried out in Terrascan.

The bald earth is subsequently extracted from the raw LiDAR points using Terrascan in a Microstation environment. The automated vegetation removal process takes place by building an iterative surface model. This surface model is generated using three main parameters: Building size, Iteration angle and Iteration distance.

The initial model is based upon low points selected by a roaming window and are assumed to be ground points. The size of this roaming window is determined by the building size parameter. These low points are triangulated and the

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remaining points are evaluated and subsequently added to the model if they meet the Iteration angle and distance constraints (fig. 1). This process is repeated until no additional points are added within an iteration.

There is also a maximum terrain angle constraint that determines the maximum terrain angle allowed within the model.

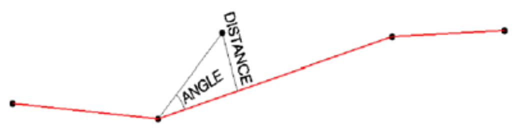

Figure 1: Terrascan iteration methodology.

(Image Source: Terrascan User's Guide, www.terrasolid.fi)

7. Quality Control

Once the data setup has taken place the manual quality control of the surface occurs. This process consists of visually examining the LiDAR points within Terrascan and correcting errors that occurred during the automated process. These corrections include verifying that all non ground elements, such as vegetation and buildings are removed from the ground model and that all small terrain undulations such as road beds, dykes, rock cuts and hill tops are present within the model.

This process is done with the help of hillshades, contours, profiles and cross-sections. To correct misclassifications, a full suite of Terrascan and custom in-house data tools are used.

8. Deliverables

Below is a list of the deliverables for this project:

All LiDAR Data Products were delivered on DVD–ROM. Two copies were provided.

Full Feature or All Return Point Data (DEM)

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- Current Pulse Return Number
- Scan Angle
- Intensity
- Classification Code (G = Ground, V = Vegetation/Non-Ground, S = Building/Structure, N = Vegetation or Building, B = Blunder)

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Aircraft Trajectory File

Time stamped GPS trajectory with location and quality metrics for all missions flown. Trajectories are delivered as Arcinfo Shape Files

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