Lowry Water Lidar Mapping Project

Sanpete and Emery Counties, UTAH

PROJECT COMPLETION REPORT

UtahStateUniversity
LASSI Service Center

Table of Contents

SUMMARY OVERVIEW

Executive Summary

The Project is located in Sanpete and Emery Counties near Spring City, Utah. The area encompasses about fifty nine (59) square miles. Data was collected on September 26, 2011 and October 24, 2011. The first mission acquired data most of the project area. The October mission was designed to improve data density in two of the canyons that experienced high relief and caused difficulties given the original flight line pattern. Vertical control was a challenge as no benchmarks could be found within the project area. A 3rd-order vertical control monument was occupied by the base station near Spring City. In the end, the GPS solution was considered the most accurate and was therefore used as the basis for project control. To the best of our knowledge, this project meets all specifications within the contract.

Contractor

This project was completed under Utah AGRC contract number UGS110915 with Utah State University LASSI Service Center signed September 15, 2011.

Primary technical point of contact formation:
Robert T. Pack, Ph.D., P.E
robert.pack@usu.edu
Utah State University
LASSI Service Center
4110 Old Main Hill
Logan, UT 84322-4110
PH 1-435-797-7049

Scope Overview

Our responsibilities included:

- Flight planning;
- Identification of ground control to be applied as airborne GPS base stations and for DEM
- processing;
- Aerial data acquisition;
- Collection of GNSS base station data during flight;
- Collection of GNSS RTK ground data for application in DEM accuracy testing;
- Processing, calibration and classification of LIDAR returns;
- Output of data deliverables including metadata;
- Compilation of Project Completion Report, including Flight, Data Processing and LIDAR DEM Accuracy reporting in compliance with National Standards for Spatial Data Accuracy (NSSDA) guidelines.

Specifications for Deliverables

The required accuracy and file formats for each delivery was as follows:

LIDAR Deliverables

Grid Projection:	UTM Zone 12N
Horizontal Datum:	NAD83 (CORS96)
Vertical Datum:	NAVD88 using GEOID09
Tile Size:	2000 m X 2000 m
Average Post Spacing:	1.0 m
Average Data Density:	1.0 sh/m^2
Vertical Accuracy	FVA of RMSEz of 12.5 cm for lidar data (USGS NGP Guidelines, v.13, 2010)
File Formats:	*.LAS (v.1.2)
Classified Datasets	ASPRS/LAS Default Classes

Grid Model Deliverables

File Format:	ArcINFO ACII (.asc)
Grid Projection:	UTM 12N
Horizontal Datum:	NAD83 (CORS96)
Vertical Datum:	NAVD88 using GEOID09
Tile Size:	2000 m X 2000 m
DEM Cell Size:	1 meter

Miscellaneous Deliverables

Hydrological Breaklines	ArcINFO shape file for entire project
Project Tile Index	ESRI shapefile with topographic map file for reference
Metadata File	FGDC compliant XML file, one file for each project, lift, and product group. Must pass USGS metadata paser.
Report	This report in PDF format

Lidar data acquisition to be accomplished using a Riegl LMS Q560 airborne laser sensor system capable of up to a maximum 200 kHz pulse repetition rate and collection of full waveform returns.

A single ground basestation collecting GPS data on one-second epochs site to be occupied during flight within 30 km of the study area.

Allowable timeframe for acquisition: As close as possible to leaf-off conditions in the Fall of 2011.

Project Area Extents and Project Tile Index and

Figure 1 illustrates the tile layout and project extents for the LIDAR survey. Tiles were designed on a 2000 m by 2000 m grid. The tile numbers were randomly generated. Note that tiles 1-4 cover the area where the GPS base station and control monument was located near Spring City.

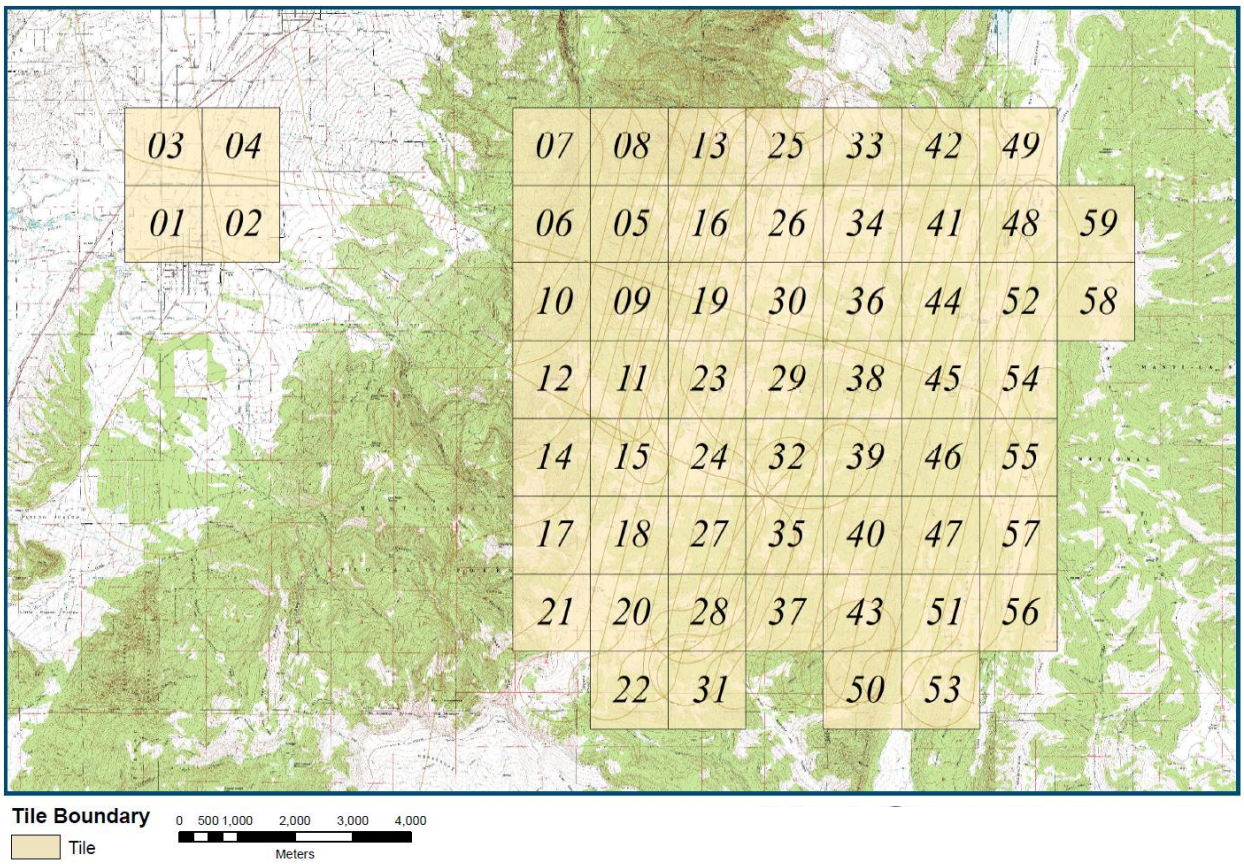

Figure 1. Tile layout and project extents.

Pre-Flight Planning

Following is a list of flight block areas and associated flightline statistics:

Study Area Summary											
Block	CASE	Mission AGL	Width (m)	Length (m)	Area (km^2)	Area (mi^2)	Nom Swath Width (m)	Nom FL Spacing (m)	# lines	Total Line Length	
LW	1	750	10000	15200	152.0	58.7	771.4	462.9	22	334.4	km

Following are the pre-flight mission parameters for the aircraft and laser scanner:

Mission Parameters:	Metric		English	
Distance to Target (Altitude)	750	m	2460.6	ft
Long-Track Velocity	118.8	kn	61.1	m/s
Flight Line Side-Lap	40	%		
Scanner Configuration:				
Swath Angle	**60**	deg		
Number of mirror faces	4			
Laser Beam Divergence	0.5	mrad		
Calculations:				
Recommended Laser PRF (for dry snow)	100	kHz	100	kHz
Required Scan Line Rate	72	Hz	72	Hz
Cross-Track IFOV	1.131	mrad	0.065	deg
Long-Track IFOV	1.131	mrad	0.065	deg
Cross-Track GSD	0.848	m	2.78	ft
Long-Track GSD	0.848	m	2.78	ft
Cross-Track FOV	1047.2	mrad	60.0	deg
Long-Track FOV (one line width)	1.131	mrad	0.065	deg
Laser Beam Footprint Size	0.40	m		
Cross-Track Nominal Width	866.0	m	2841.3	ft
Long-Track Nominal Width (one line)	0.8	m	2.8	ft
Shot Density	1.4	sht/m2	1.66	s/yd2

Following is a map showing the flight plan for the subject area. The area was initially planned with the regular flightline pattern that extends across the entire area. A second mission was planned for the subareas shown in order to pick up extra data in the canyons where data density issues were

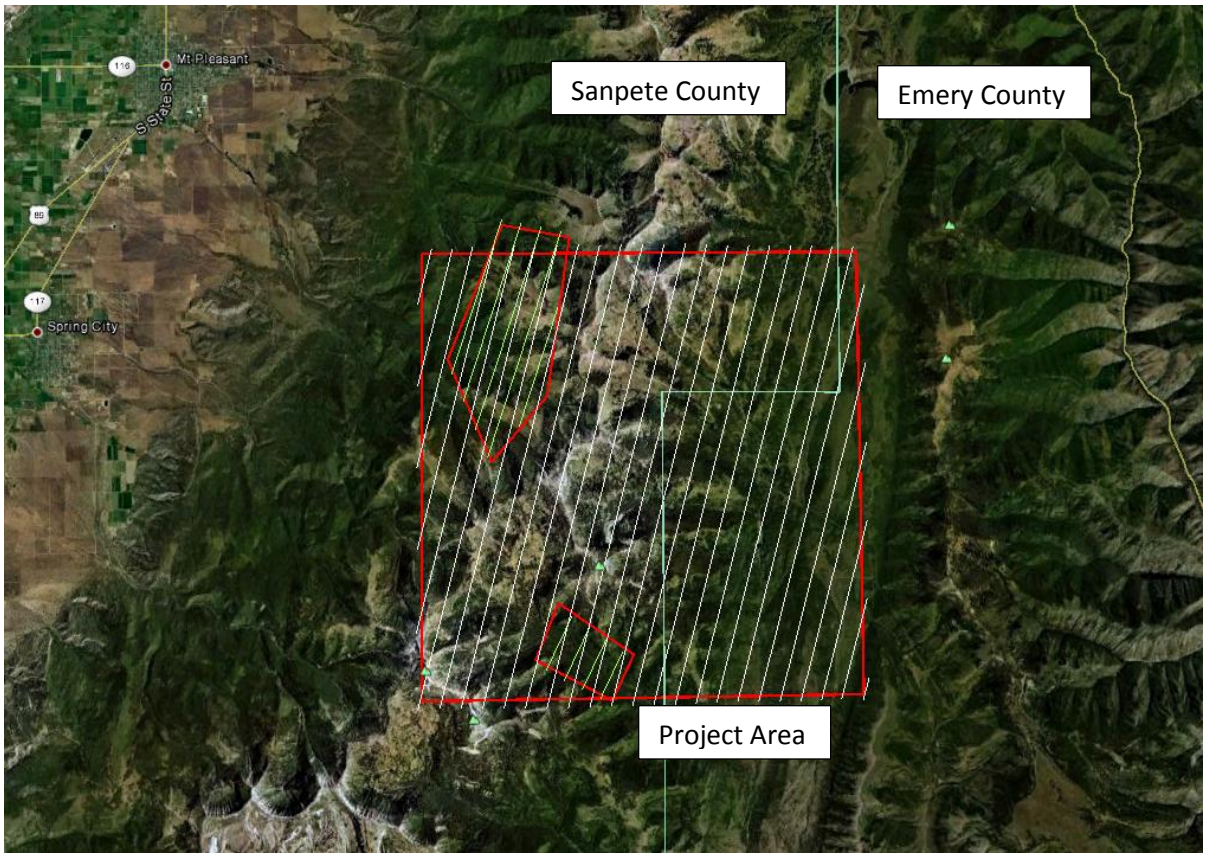

Figure 2. Flight line layout.

Control

The area surrounding the study area was searched for candidate vertical control monmuments over which the GPS ground station could be placed. The goal was to get strong vertical control, while at the same time, be within 10 km of the study area. Only one ground control location near Spring City was selected as base-stations for the purpose of collecting GPS information during flight. This control point is NGS PID KN0377 – SPRING.

```
**********************************************************************
KN0377  DESIGNATION -  SPRING
KN0377  PID         -  KN0377
KN0377  STATE/COUNTY-  UT/SANPETE
KN0377  USGS QUAD   -  MOUNT PLEASANT (1978)
KN0377
KN0377                        *CURRENT SURVEY CONTROL
KN0377
_____________________________________________________________________
KN0377* NAD 83(1994)-  39 30 01.10568(N)     111 29 19.22566(W)
ADJUSTED
KN0377* NAVD 88     -      1770.54   (+/-2cm)     5808.8     (feet)
VERTCON
KN0377
_____________________________________________________________________
```

```
KN0377  LAPLACE CORR-          11.12  (seconds)
DEFLEC09
KN0377  GEOID HEIGHT-         -17.13  (meters)
GEOID09
KN0377  HORZ ORDER  -  SECOND
KN0377  VERT ORDER  -  THIRD ? (See Below)
```

NGS Data sheets are attached to this report in softcopy format. No new establishment of ground control stations was planned. At this base station, GPS data would be collected on one-second epochs for the duration of the aerial acquisition.

Final Planning – Procedures and Activities

Planning

Weather forecasts and project schedule identified an aerial acquisition window during the week of September 25, 2011. Because of the high elevation of this site, and after consultation with Steve Bowman, our POC at the Utah Geological Survey, it was decided to proceed during this week, even though leaf-drop conditions were not yet ideal. On September 24, 2011, the following was completed:

- Brief aircrew and surveyors on project requirements
- Investigate PDOP forecast for location (Flights to be conducted with PDOP below 3.0)
- Decision to mobilize Bob Pack to site to set up targets and GPS base stations.
- Complete a reconnaissance of the project area was conducted to report on ground conditions.

This project flight was planned for and completed on September 26, 2011. The aircraft was mobilized out of Logan, Utah and the entire project, including the comute, was completed in one day.

After the first flight, it was determined that two canyons required supplimental data. As second flight was therefore planned for October 24, 2011. Fortunately, the areas requiring the reflight were snow free on that date.

Summary of Supporting Documents

- PID KN0377 SPRING NGS DATASHEET.htm– *NGS Data Sheet for Station KN0377*
- Lowry PDOP Plot September 25 2011.jpg – *PDOP forecast for September 25, 2011.*
- Lowry PDOP Plot October 24 2011.jpg – *PDOP forecast for October 24, 2011.*

(The above listed documentation is provided in softcopy format only.)

Data Processing Procedures Report

Data Storage

Data collection of the survey area resulted in a total of twenty six (26) flight lines covering the project area. An additional nine (9) flight lines were flown during a second flight in October. After each flight, all raw navigation data, raw lidar data, raw image data, coverage data, and flight logs were offloaded to a computer and an additional backup storage copy created.

Navigation System

The airborne GPS data were processed from one base station using GrafNet software from NovAtel. Data was also collected from the following IGS stations for the period of the flight:

Station	Latitude (D M S)	Longitude (D M S)	Grid-E (m)	Grid-N (m)	EllHgt (m)
CAST	39 11 27.67849	-110 40 38.33101	6177583.430	7109974.786	2245.044
P109	39 35 50.94783	-111 39 03.00128	6053829.726	7045192.672	1760.955
PUC1	39 35 57.08358	-110 48 31.37983	6113313.094	7131725.042	1692.499
SPIC	39 18 22.37046	-112 07 38.91341	6057280.611	6970916.094	1670.425

Airborne GPS data was processed based on the ITRF05 Ellipsoid model. The network solution for the IGI points was as follows:

STA. NAME	-- RE -- (m)	-- RN -- (m)	-- RH -- (m)
CAST	0.0002	-0.0013	0.0171
P109	0.0011	0.0005	0.0035
PUC1	0.0010	-0.0003	-0.0051
SPIC	-0.0026	0.0010	-0.0154
RMS	0.0015	0.0009	0.0119

The ITR05 base-station coordinate was determined to be:

STA_ID	-- LATITUDE --	-- LONGITUDE --	- ELLHGT -
GPS@SPRING	39 30 01.12633	-111 29 19.28049	1752.7240

These trajectories and the base station coordinate were used in the processing of the IMU data using Inertial Explorer from Waypoint. A smoothed trajectory is produced with error estimates based on the separation between trajectories processed forward in time and backward in time. Following this step, the estimated XY error (0.5 times the separation) dropped to 2 cm and the Z error to less than 3.5 cm. The roll and pitch error to less than 1 arcmin and the yaw error to less than 3 arcmin. This trajectory file was then transformed to the NAD83(CORS96) & NAVD88(GEOID09) project datum and the UTM Zone 12N projection for use in the lidar processing.

Lidar System

Lidar waveform files were analyzed using RiAnalyze software to discriminate data points. These points are output in the internal coordinate system of the lidar scanner. Each data point is assigned an echo value so it can be used in point classification work. RiProcess then uses the trajectory files created from the raw navigation data to generate XYZ points in a world coordinate system. A boresite calibration and strip (single scan line) adjustment was performed in RiProcess to improve data accuracy. This project's data were processed in strip form, meaning each flight line was processed independently. Processing the lines individually provides the data analyst with the ability to QC the overlap between lines. To assess trajectory integrity, individual flight strips were then

checked against adjacent strips to ensure good matching in the dataset.

Each flightline (strip) was then brought into Terrascan (by TerraSolid) in the project datum and coordinate system. These flightlines were then combined and several classification routines, customized for the given terrain and vegetation, were then run to classify the points into standard ASPRS/LAS default classifications. A Triangular Irregular Network (TIN) and associated contours were then generated using the final bare-earth data and checked for quality.

LIDAR QUALITY CONTROL REPORT

Methodology

The accuracy of lidar data is estimated by determining the vertical root mean square error (RMSEz). RMSEz is the square root of the average of the set of squared differences between dataset vertical coordinate values and vertical coordinate values from an independent source of higher accuracy for identical points. If those differences are normally distributed and average zero, 95 percent of any sufficiently large sample should be less than 1.96 times the RMSEz. Therefore 15 cm RMSEz is often referred to as "30cm accuracy at the 95-percent confidence level". Following that convention, the vertical accuracy of any lidar dataset is defined as 1.96 times the RMSEz of linearly interpolated elevations in the dataset, as compared with known elevations from high-accuracy test points.

The Quality Control check was intended to ensure that data would meet contractual standards set in FEMA (2003, Section A.8) and USGS NGP Guidelines v.13 (2010). Following is a summary of there standards for RMSEz:

RMSEz	Condition	Source
7.0 cm	Relative accuracy within individual swaths	USGS
10.0 cm	Within swath overlap regions	USGS
12.5 cm	Fundamental vertical accuracy (in the clear)	USGS
18.5 cm	Under all major vegetation categories in flat areas	FEMA
37.0 cm	Under all major vegetation categories in hilly areas	FEMA

The Lowry Water project area is remote and therefore finding a GPS Base Station control point close enough to the area to enable convenient RTK GPS field truthing was problematic. It was therefore proposed and accepted by AGRC that a 5' diameter lidar target be used as a spot check. This target was placed next to the SPRING NGS monument near Spring City (see Figure 3). The strategy was to fly over the base station enroute to the Lowry Water flightlines and compare the height of the target (leveled from SPRING) with the lidar point(s) that fell on the target. Figure 4 shows a lidar-derived TIN of the target site next to Highway 117. Queries show the data for three lidar shots, two of which landed on the target (circle) and one of which landed on the SPRING NGS monument. The two shots on the target are at 1771.34 m and the one on the monument is at 1770.64. This difference in height sensed by the lidar is within one centimeter of being same as that measured by the survey level in the field. This indicates relative accuracy well under the 7.0 cm USGS requirement. Note that the target height reported in this report is 6 cm higher than the height reported in our original flight report dated November 3, 2011. This is due to an error in the original reporting where the fact that the

table had been repositioned and re-leveled was missed when reviewing the field notes.

The absolute height of the monument as measured by the base station is 7 cm below that measured by the lidar. Table 1 shows the data supporting these results. This single check on lidar accuracy suggests that there are no datum/methodology issues in the data processing – and that the absolute accuracy is likely to be well within the required 12.5 RMSEz USGS requirement.

Conclusions

Given the spot check of lidar accuracy at the SPRING NGS monument, it is likely that the survey areas are within the required specifications.

- There is a tested <1 cm RMSEz relative accuracy.
- There is a tested 7 cm RMSEz fundamental vertical accuracy.

Figure 3. Lidar target next to NGS PID KN0377 “SPRING” monument occupied by the USU GNSS base station.

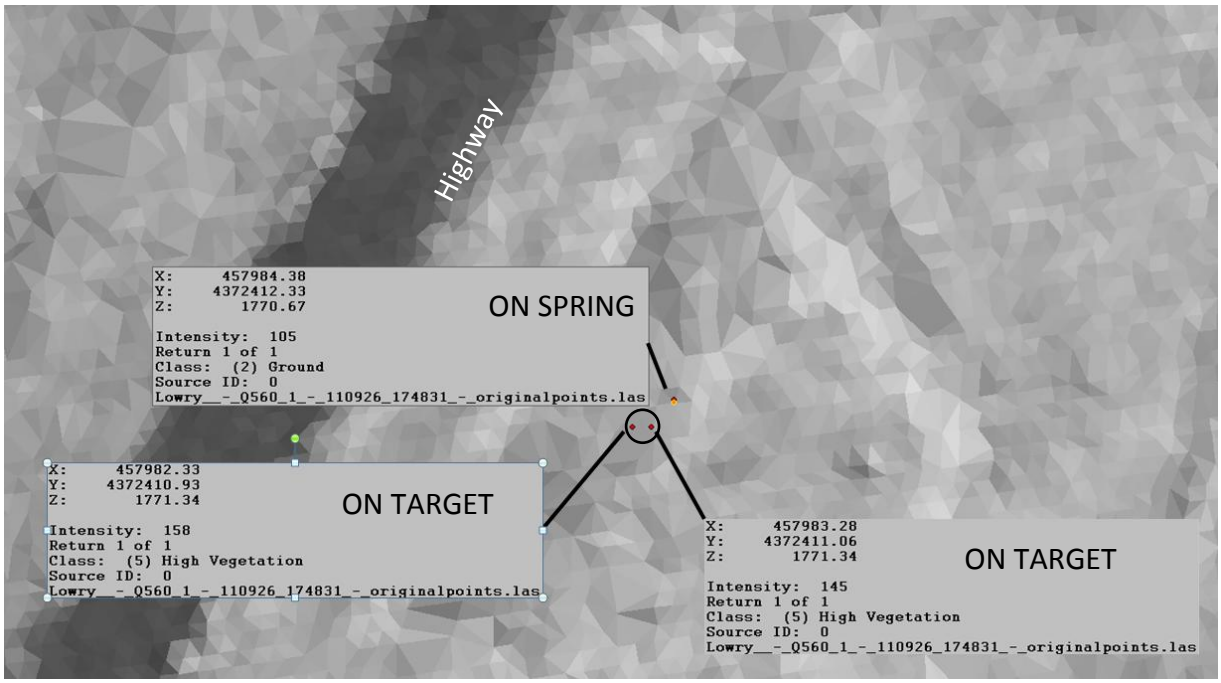

Figure 4. Lidar derived TIN of the target site next to Highway 117. Queries show the data for three lidar shots, two of which landed on the target (circle) and on of which landed on the SPRING NGS monument. The TIN is colored by shot intensity. Note that the target is not white in the 1.5 um IR bandwidth.

Table 1. Comparison of GPS and lidar measurements at the SPRING NGS Monument.

POINT	COORDINATE 3		SOURCE
GPS & LIDAR MEASUREMENTS			
GPS @ SPRING	1752.724	ELLHGT	DATA INPUT
GPS @ SPRING	1753.466	ELLHGT	Waypoint XFRM ITRF05 to CORS96
GPS @ SPRING	1770.60	ORTHGT	Blue Marble HTDP XFRM on GEOID09
PID KN0377 - SPRING	1770.67	ORTHGT	Lidar Point
DELTA GPS/LIDAR	-0.07		Lidar is 7 cm high
TARGET @ SPRING	1771.27	ORTHGT	Field Notes - Relative to SPRING
TARGET @ SPRING	1771.34	ORTHGT	2 Lidar Points in Target
DELTA GPS/LIDAR	-0.07		Lidar is 7 cm high

FLIGHT REPORT

USU's Cessna 208B Skywagon remote sensing aircraft, N4630F, based out of Logan, UT was utilized on this project. This aircraft was mobilized out of Logan Municipal Airport, Utah.

Data collection of the survey area resulted in a total of twenty six (26) flight lines covering the project area on September 25, 2011. An additional nine (9) flight lines were flown during a second flight on October 24, 2011. These lines were flown at a nominal 120-knot ground speed, 750 meters above ground level and took approximately 2.5 hours in

September and less than an hour in October to complete.

One base station located to the west of the project area was used to support the precise positioning of the on-board sensors during the duration of each flight. The base station was a NovAtel DL4+ unit with a 702 GG 1.02 antenna operated by LASSI Service Center.

The actual local flight times and duration of flights were controlled by weather, fuel consumption of the aircraft on the comute from Logan, Utah, and safety of flight operations in this mountainous region. This limited our flexibility in planning for times when the GPS constellation was most favorable thereby producing the highest number of satellites visible in the best geometric configuration relative to the GPS receivers onboard the aircraft as well as at the master stations on the ground.

The LIDAR acquisition was completed in two days. Data collection of thirty one (31) flightlines on September 26, 2011 started around 17h48 UTC and ended around 18h19 UTC on the same day. The second set of ten (10) flightlines were flown on October 24, 2011 between 17h51 UTC and 18h19 UTC.
Following is a list of files acquired during these two missions.

Navigation File(s): Remote_20110926_01, Remote_20110926_02, Remote_20111024

Base Station File(s): 00052691.pdc

Raw Flightline (LIDAR) File(s):

110926_174831.sdf	110926_190355.sdf	110926_224632.sdf
110926_175949.sdf	110926_190912.sdf	110926_224831.sdf
110926_180218.sdf	110926_191421.sdf	110926_225115.sdf
110926_180716.sdf	110926_191935.sdf	111024_175151.sdf
110926_181101.sdf	110926_192435.sdf	111024_175528.sdf
110926_181632.sdf	110926_192947.sdf	111024_175734.sdf
110926_182126.sdf	110926_193500.sdf	111024_180001.sdf
110926_182657.sdf	110926_194205.sdf	111024_180227.sdf
110926_183222.sdf	110926_194744.sdf	111024_180456.sdf
110926_183750.sdf	110926_195235.sdf	111024_180822.sdf
110926_184315.sdf	110926_195741.sdf	111024_181153.sdf
110926_184821.sdf	110926_200139.sdf	111024_181601.sdf
110926_185332.sdf	110926_200459.sdf	111024_181931.sdf
110926_185846.sdf	110926_200727.sdf	

GROUND CONTROL REPORT

Introduction

A lidar survey was conducted for the purposes of developing a high-accuracy DTM of the Lowry Water project area. The data is intended to be used by the State of Utah for general public use. The LIDAR survey collected the the usual terrain information.

Applicable Standards

The following standards apply to this geodetic control survey: Geospatial Positioning Accuracy Standards.

- Part 1: Reporting Methodology (FGDC-STD-007.1-1998)
- Part 2: Standards for Geodetic Networks (FGDC-STD-007.2-1998)
- NOAA Technical Memorandum NOS NGS-58, Guidelines for Establishing GPS Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)
- DRAFT NOAA Technical document, Guidelines for Establishing GPS-derived Orthometric Heights (Standards: 2 cm and 5 cm)

Ground Control Survey

A GPS static network adjustment was performed for the purpose of establishing three-dimensional coordinates of the GNSS base station located over the SPRING monument used for airborne control. This network incorporated three published IGS control points:

Station	Latitude (D M S)	Longitude (D M S)	Grid-E (m)	Grid-N (m)	EllHgt (m)
CAST	39 11 27.67849	-110 40 38.33101	6177583.430	7109974.786	2245.044
P109	39 35 50.94783	-111 39 03.00128	6053829.726	7045192.672	1760.955
PUC1	39 35 57.08358	-110 48 31.37983	6113313.094	7131725.042	1692.499
SPIC	39 18 22.37046	-112 07 38.91341	6057280.611	6970916.094	1670.425

Data Collection

Baselines between all points were collected on September 26, 2011. All observations conducted at the SPRING monument were made with a NovAtel dual-frequency GPS receiver. The session length was approximately 7 hours. During the October 24, 2011 mission, logisitcal challenges prevented the use of a local base station.

Data Processing and Analysis

The GNSS network adjustment used followed the following steps:

1) Complete a traverse solution to detect network station coordinate blunders.
2) Complete a weighted GPS network adjustment .
3) Convert the SPRING NGS monument to the CORS96 project datum
4) Compare the difference between the GPS and NGS solutions

1 - GrafNet Traverse Solution

```
DATUM:  ITRF05
GRID:   UTM, Zone 1
UNITS:  metres
GEOID:  (none)

*******************************
  STATIONS (COORDINATES):
*******************************
```

Station	Latitude (D M S)	Longitude (D M S)	Grid-E (m)	Grid-N (m)	EllHgt (m)	OrthoHgt (m)
00052691	**39 30 01.12643**	**-111 29 19.28044**	**6078210.678**	**7053084.080**	**1752.705**	(-)

```
CAST      39 11 27.67849 -110 40 38.33101  6177583.430  7109974.786  2245.044       (-)
P109      39 35 50.94783 -111 39 03.00128  6053829.726  7045192.672  1760.955       (-)
PUC1      39 35 57.08358 -110 48 31.37983  6113313.094  7131725.042  1692.499       (-)
SPIC      39 18 22.37046 -112 07 38.91341  6057280.611  6970916.094  1670.425       (-)


*******************************
LOOP, CHECK & DUPLICATE TIES:
*******************************

Name/Session                     Type      Result    DEast    DNorth   DHeight
                                                       (m)      (m)       (m)
P109 to 00052691                 LoopTie   Good     0.0026   0.0052  -0.0145
PUC1 to 00052691                 LoopTie   Good    -0.0035   0.0044  -0.0277
SPIC to 00052691                 LoopTie   Good    -0.0007   0.0017  -0.0326
                                                  ----------------------------
RMS (tie points)                                     0.0025   0.0041   0.0261
RMS (check points)
                                                  ============================
```

2 - GrafNet Weighted GPS Network Adjustment

```
             ************************************************
             * NETWORK - WEIGHTED GPS NETWORK ADJUSTMENT      *
             *                                                *
             * (c) Copyright NovAtel Inc., (2011)             *
             *                                                *
             * Version: 8.30.2105                             *
             *                                                *
             * FILE: BaseStation_SPRING_Lowry_20110926.net
             ************************************************

DATE(m/d/y): Fri.   2/10/12   TIME:  9:07:48

*************************************************************
  DATUM:            'ITRF05'
  SCALE_FACTOR:     1.4680
  CONFIDENCE LEVEL: 39.40 %   (Scale factor is 1.0009)

*************************************************************
    INPUT CONTROL/CHECK POINTS
*************************************************************

STA_ID     TYPE    -- LATITUDE --  -- LONGITUDE --  ELLHGT -   HZ-SD   V-SD
CAST       GCP-3D  39 11 27.67849 -110 40 38.33101   2245.044 0.00500 0.00500
P109       GCP-3D  39 35 50.94783 -111 39 03.00128   1760.955 0.00500 0.00500
PUC1       GCP-3D  39 35 57.08358 -110 48 31.37983   1692.499 0.00500 0.00500
SPIC       GCP-3D  39 18 22.37046 -112 07 38.91341   1670.425 0.00500 0.00500

*************************************************************
    INPUT VECTORS
*************************************************************

SESSION NAME           VECTOR(m)    ------ Covariance (m) [unscaled] ------
                        DX/DY/DZ           standard deviations in brackets
CAST to 00052691 (1)  -57310.4591  4.0740e-006 (0.0020)
                      45841.6407  -3.4695e-007 6.4453e-006 (0.0025)
                      26251.0636  -4.3046e-007 -2.3429e-006 2.0630e-006 (0.0014)

P109 to 00052691 (1)  10440.5661  4.7489e-007 (0.0007)
                      -11509.3925  4.2473e-007 1.4877e-006 (0.0012)
                      -8326.4979  -2.7061e-007 -8.3153e-007 1.1501e-006 (0.0011)

P109 to CAST (1)      67751.0291  2.9761e-006 (0.0017)
                      -57351.0318  9.2469e-008 2.5932e-006 (0.0016)

                     -34577.5587  -4.5014e-007 -1.1284e-006 1.2369e-006 (0.0011)

PUC1 to 00052691 (1)  -57062.3282  7.0847e-006 (0.0027)
                      14527.5937  -6.6711e-007 1.1306e-005 (0.0034)
                      -8428.7034  -7.3944e-007 -4.1229e-006 3.6392e-006 (0.0019)

PUC1 to CAST (1)        248.1285  4.1988e-006 (0.0020)
```

```
                      -31314.0406  1.3303e-007 3.6388e-006 (0.0019)
                      -34679.7669  -6.1727e-007 -1.5865e-006 1.7390e-006 (0.0013)

PUC1 to P109 (1)      -67502.9005  4.9496e-006 (0.0022)
                      26036.9914  1.3078e-007 4.3285e-006 (0.0021)
                       -102.2085  -7.4747e-007 -1.8831e-006 2.0729e-006 (0.0014)

SPIC to CAST (1)      113465.9425  3.8500e-006 (0.0020)
                      -53642.7160  1.0963e-007 3.3843e-006 (0.0018)
                      -9543.1175  -5.8689e-007 -1.4615e-006 1.5948e-006 (0.0013)

SPIC to 00052691 (1)  56155.4812  3.5027e-006 (0.0019)
                      -7801.0730  -3.8737e-007 5.7129e-006 (0.0024)
                      16707.9461  -3.7276e-007 -2.0551e-006 1.8073e-006 (0.0013)

SPIC to P109 (1)      45714.9131  2.1415e-006 (0.0015)
                       3708.3155  4.5315e-008 1.9043e-006 (0.0014)
                      25034.4412  -3.3322e-007 -8.2000e-007 9.0086e-007 (0.0009)

SPIC to PUC1 (1)      113217.8123  8.1465e-006 (0.0029)
                      -22328.6790  8.2730e-007 7.2680e-006 (0.0027)
                      25136.6509  -1.5910e-006 -3.2075e-006 3.2970e-006 (0.0018)

*****************************************************************
    OUTPUT VECTOR RESIDUALS (East, North, Height - Local Level)
*****************************************************************

SESSION NAME               -- RE --   -- RN --   -- RH --     - PPM -   DIST - STD -
                              (m)        (m)        (m)                    (km)    (m)
CAST to 00052691 (1)       -0.0015    -0.0017     0.0016       0.036   77.9  0.0043
P109 to 00052691 (1)        0.0004     0.0017     0.0007       0.105   17.6  0.0021
P109 to CAST (1)           -0.0012    -0.0005    -0.0005       0.015   95.3  0.0032
PUC1 to 00052691 (1)       -0.0055     0.0017    -0.0039       0.117   59.5  0.0057
PUC1 to CAST (1)            0.0006     0.0000    -0.0016       0.037   46.7  0.0037
PUC1 to P109 (1)            0.0017     0.0006    -0.0007       0.027   72.4  0.0041
SPIC to CAST (1)           -0.0007     0.0001    -0.0011       0.011  125.9  0.0036
SPIC to 00052691 (1)        0.0007    -0.0024     0.0015       0.050   59.1  0.0040
SPIC to P109 (1)            0.0006     0.0009    -0.0009       0.027   52.3  0.0027
SPIC to PUC1 (1)           -0.0010     0.0015    -0.0035       0.033  118.1  0.0052
                         ---------------------------------
               RMS          0.0020     0.0013     0.0020

 $ - This session is flagged as a 3-sigma outlier

*****************************************************************
    CONTROL POINT RESIDUALS (ADJUSTMENT MADE)
*****************************************************************

STA. NAME     -- RE --   -- RN --   -- RH --
                 (m)        (m)        (m)
CAST           0.0002    -0.0013     0.0171
P109           0.0011     0.0005     0.0035
PUC1           0.0010    -0.0003    -0.0051
SPIC          -0.0026     0.0010    -0.0154
            ---------------------------------
RMS            0.0015     0.0009     0.0119

*****************************************************************
    OUTPUT STATION COORDINATES (LAT/LONG/HT)
*****************************************************************

STA_ID       -- LATITUDE --   -- LONGITUDE -- - ELLHGT -
00052691     39 30 01.12633 -111 29 19.28049  1752.7240
CAST         39 11 27.67845 -110 40 38.33100  2245.0610
P109         39 35 50.94784 -111 39 03.00124  1760.9583
PUC1         39 35 57.08357 -110 48 31.37979  1692.4938
SPIC         39 18 22.37049 -112 07 38.91352  1670.4095

*****************************************************************
    OUTPUT VARIANCE/COVARIANCE
*****************************************************************
                                          2
STA_ID       SE/SN/SUP  --------- CX matrix (m )-----------
```

```
            (39.40 %)  (not scaled by confidence level)
               (m)           (ECEF, XYZ cartesian)
00052691       0.0026  7.0119e-006
               0.0026  1.6984e-007 7.6853e-006
               0.0028  -1.7673e-007 -6.2010e-007 6.9242e-006

CAST           0.0026  7.0152e-006
               0.0025  1.3702e-008 6.9804e-006
               0.0027  -1.0988e-007 -3.0657e-007 6.5855e-006

P109           0.0026  6.8016e-006
               0.0025  2.4122e-008 6.8405e-006
               0.0026  -8.8938e-008 -2.5410e-007 6.5343e-006

PUC1           0.0027  7.3719e-006
               0.0026  3.1183e-008 7.3191e-006
               0.0028  -1.6823e-007 -4.4791e-007 6.7396e-006

SPIC           0.0027  7.0343e-006
               0.0025  1.6827e-008 7.0148e-006
               0.0027  -1.1987e-007 -3.1833e-007 6.5939e-006

*****************************************************************
    VARIANCE FACTOR = 1.0128

    Note: Values < 1.0 indicate statistics are pessimistic, while
          values > 1.0 indicate optimistic statistics. Entering this
          value as the network adjustment scale factor will bring
          variance factor to one.
*****************************************************************
```

3 – Comparison of GrafNet Resuits with NGS Coordinate

Both the GPS coordinates and the NGS coordinates were transformed to the NAD83(CORS96) UTM Zone 12N, NAVD88(Geoid09) project datums for camparison. The following table reports the results. It can be seen that the vertical difference is 0.056 cm. The tranform of the GrafNet ITRF05 result to the NAD83(CORS96) project datum is probably pretty solid, at least to a couple of centimeters. The reliability of the 3rd order vertical control at SPRING was researched by Dave Doyle at NGS . The NAVD 88 height for SPRING is Third-Order, which is the lowest defined national standard. He found out that this height was determined by a spur level run from a single existing bench mark and was used primarily to reduce other observations in the triangulation network back in the 1930s. In his words, “NGS would not recommend using such a height as the source for control for any program that requires well defined heights.” Therefore, in the end the SPRING monument is not deemed accurate enough adjustment of lidar survey to match this benchmark. But it will have served well as a sanity check.

POINT	PROJ	DATUM	GEOID	REAL	COORDINATE 1		COORDINATE 2		COORDINATE 3	
GPS @ SPRING		ITRF05		2005	39 30 01.12633	LAT	-111 29 19.28049	LON	1752.724	ELLHGT
GPS @ SPRING		NAD83		CORS96	39 30 01.10938	LAT	-111 29 19.22974	LON	1753.466	ELLHGT
GPS @ SPRING	UTM12N	NAD83	GEOID09	CORS96	4372412.68	N	457984.30	E	1770.60	ORTHGT
KN0377-SPRING		NAD83		HARN	39 30 01.10568	LAT	-111 29 19.22566	LON	1753.41	ELLHGT
KN0377-SPRING		NAD83	GEOID09	HARN	4372412.57	N	457984.40		1770.54	ORTHGT
KN0377-SPRING		NAD83		CORS96	39 30 01.10646	LAT	-111 29 19.22408	LON	1753.378	ELLHGT
KN0377-SPRING	UTM12N	NAD83	GEOID09	2007		N		E	1770.508	ORTHGT
DIFFERENCE	UTM12N	NAD83	GEOID09	CORS96	0.110	N	-0.100	E	0.056	ORTHGT

Local Control Data Sheets

Following is the data sheet and photographs of the NGS PID=KN0377 “SPRING” Data Sheet.

```
******************************************************************************
 KN0377  DESIGNATION -  SPRING
 KN0377  PID         -  KN0377
 KN0377  STATE/COUNTY-  UT/SANPETE
 KN0377  USGS QUAD   -  MOUNT PLEASANT (1978)
 KN0377
 KN0377                         *CURRENT SURVEY CONTROL
 KN0377  ______________________________________________________________________
 KN0377* NAD 83(1994)-  39 30 01.10568(N)     111 29 19.22566(W)      ADJUSTED
 KN0377* NAVD 88     -      1770.54   (+/-2cm)    5808.8    (feet)   VERTCON
 KN0377  ______________________________________________________________________
 KN0377  LAPLACE CORR-          11.12  (seconds)                     DEFLEC09
 KN0377  GEOID HEIGHT-        -17.13  (meters)                      GEOID09
 KN0377  HORZ ORDER  -  SECOND
 KN0377  VERT ORDER  -  THIRD ? (See Below)
 KN0377
 KN0377.The  horizontal  coordinates  were  established  by  classical  geodetic
methods
 KN0377.and adjusted by the National Geodetic Survey in November 1997.
 KN0377.
 KN0377.The NAVD 88 height was computed by applying the VERTCON shift value to
 KN0377.the NGVD 29 height (displayed under SUPERSEDED SURVEY CONTROL.)
 KN0377
 KN0377.The vertical order pertains to the NGVD 29 superseded value.
 KN0377
 KN0377.The Laplace correction was computed from DEFLEC09 derived deflections.
 KN0377
 KN0377.The geoid height was determined by GEOID09.
 KN0377
 KN0377;                    North         East     Units Scale Factor Converg.
 KN0377;SPC UT C     - 2,129,555.965   500,974.119   MT  0.99991578   +0 00 26.1
 KN0377;SPC UT C     - 6,986,718.20  1,643,612.59   sFT  0.99991578   +0 00 26.1
 KN0377;UTM  12      - 4,372,412.565   457,984.396   MT  0.99962173   -0 18 39.0
```