Cedar Valley, Hurricane Fault, Ogden Valley, and Lowry Water LiDAR Acquisition

Iron, Emery, Sanpete, Washington, and Weber Counties, Utah

COMPLETION REPORT

UtahStateUniversity
LASSI Service Center

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SUMMARY OVERVIEW

Executive Summary

This project encompasses four areas in five Utah counties and encompasses about 617 square miles shown below. Data was collected in September and October, 2011.

Study Area	County	Size (mi²)
Cedar Valley & Hurricane Fault	Iron	499
Lowry Water	Sanpete and Emery	59
Ogden Valley	Weber	59
Total		617

Contractor

This project was completed under contract number UGS110915 between Utah Automated Geographic Reference Center (Utah AGRC) and Utah State University (USU) LASSI Service Center .

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Scope Overview

Our responsibilities included:

- Flight planning;
- Identification of ground control to be applied as airborne GNSS 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:

<u>LiDAR Deliverables</u>

Grid Projection:	UTM Zone 12N
Horizontal Datum:	NAD83(CORS96)
Vertical Datum:	NAVD88 using GEOID09
Tile Size:	2000 m X 2000 M
Average Post Spacing:	0.85 m
Average Data Density:	1.37 sh/m2
File Formats:	*.las (v. 1.2)
Classified Datasets:	ASPRS/LAS Default Classes

<u>Grid Model Deliverables</u>

File Format:	IMG (.img)
Grid Projection:	UTM Zone 12N
Horizontal Datum:	NAV83(CORS96)
Vertical Datum:	NAVD88 using GEOID09
Tile Size:	2000 m X 2000 m
Cell Size:	1.00m

<u>Miscellaneous Deliverables</u>

Breakpoint Files:	LAS 1.2 (.las) on specific code
Metadata Files:	FGDC compliant XML file. (.xml)
Project Tile Index:	Portable Document Format (.pdf)
Completion Report:	Portable Document Format (.pdf)

LiDAR data acquisition was performed 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.

Project Area Extents and Project Tile Index

The tile layout and project extents for the five areas surveyed are provided in Appendix A. The number of tiles is summarized in Table 1.

Table 1. Project areas.

Area	Number of Tiles
Cedar Valley	385
Hurricane Fault	61
Ogden Valley	65
Lowry Water	59

Tiles were designed on a 2000 m by 2000 m grid and were automatically generated.

Pre-Flight Planning

Table 2 provides a list of flight block areas and associated flightline statistics:

Table 2. Flight block areas.

Area	Flight AGL (m)	Spacing (m)	Number of Lines	Line Kilometers
Cedar Valley	750	460	201	2396
Hurricane Fault	750	460	6	116
Ogden Valley	750	460	44	281
Lowry Water	750	460	22	334

Table 3 provides the pre-flight mission parameters for the aircraft and laser scanner:

Table 3. Pre-flight mission parameters.

Mission Summary	750 m AGL	
	Riegl Q560	
	Metric	English
GSD - Cross Track	0.848 m	2.8 ft
GSD - Long Track	0.848 m	2.8 ft
Data Density	1.4 sh/m2	0.13 sh/ft2
Shot/Pixel Size	0.40 m	1.3 ft
Swath Width	866.0 m	2840.6 ft
Flightline Spacing	519.6 m	1704.3 ft
Shot or Frame Rate	67 kHz	
Total Numbers	0.55 Gpoints	

The flight plans for the subject areas are found in Appendix B.

Control

The area surrounding the study area was searched for candidate vertical control monuments over which the GNSS ground station could be placed. The goal was to tie to A- or B-order vertical control, while at the same time, be within 10 km of the study area. Table 4 provides a list of ground control stations used for this project.

The benchmarks were selected on the basis of (1) vertical accuracy, (2) accessibility, and (3) security for targets and the GPS base station. Five GPS base stations were established. One station in Ogden Valley (WOLF) and Lowry Water (SPRING) were occupied for most of a day each. Q 376 and H 28 GPS stations in Cedar Valley were occupied about 2 days each and C364 on Hurricane Fault for most of one day. This enabled the calculation of strong static GPS solutions which have been compared with the published vertical coordinates.

At each of the stations, 5-foot diameter white circular targets were established, an example of which is shown in Figure 1 for station Y 351. The surface of each target was leveled using a five foot long construction level. The target height was then determined using an automatic level. This was done using a back-sight to the monument and a fore-sight to the table surface (see Figure 1). The accuracy of the target height relative to the monument was consistently within about 1 cm. All ten targets were scanned by the lidar in at least one flightline.

The GPS base stations were set up directly over the given monument (with the exception of monument C 364 near LaVerkin, Utah) and the height to the antenna measured within 1 mm. In the case of Station C 364, the monument was at the base of a cliff in an area of poor GPS satellite visibility. A steel pin was therefore established for the GPS station and the pin's height was accurately measured relative to the control point using an automatic level. This was used to compare calculated coordinates with published coordinates. In order to make proper comparisons, the heights measured at previous dates needed to be adjusted according to observed HTDP point velocities published by NGS for nearby CORS stations. These points were thereby brought up to date.

Figure 1. Example of lidar target along with equipment used to level its height relative to a nearby benchmark.

Final Planning – Procedures and Activities

Planning

Weather forecasts and project schedule identified an aerial acquisition window during the months of September and October 2011. Prior to each acquisition campaign, the following was completed:

- Brief flight crew and ground support personnel 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 GNSS base stations.
- Complete a reconnaissance of the project area was conducted to report on ground conditions.

It was planned such that each time the aircraft was mobilized out of Logan, Utah each of the four areas could be completed during a single block of days. The exception to this rule was made for the Lowry Water area where after the first flight, it was determined that two canyons required supplemental 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

- CV NGS DATASHEETS.htm– *NGS Data Sheets NGS benchmarks used*
- PDOP Plots subdirectory – contains *PDOP forecasts for periods of data acquisition.*

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

Data Processing Procedures Report

Data Storage

After each flight, all raw navigation data, raw LiDAR data, raw image data, coverage data, and flight logs were off-loaded to a computer and an additional backup storage copy created.

Navigation System

The airborne GNSS data were processed from the five base station locations using GrafNet software from NovAtel. Data was also collected from nearby International GPS Service for Geodynamics (IGS) stations for the periods of the flight. Airborne GNSS data was processed based on the ITRF05 Ellipsoid model.

The computed trajectories and the base station coordinates were used in the processing of the IMU data using Inertial Explorer from Waypoint. A smoothed trajectory was produced with error estimates based on the separation between trajectories processed forward and backward in time. The trajectory files were then transformed to the NAD83(CORS96) and 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 boresight 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 quality control (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.

A custom strip overlap adjustment method has been developed that not only optimize the lidar system calibration but also correct GPS/IMU navigation errors manifested within individual strips. This method corrects for aircraft roll and aircraft altitude error detected by analyzing elevation differences in all overlapping strips simultaneously. Figure 2 shows an example color-coded map of overlapping regions where blue equals a -10 cm difference, cyan a -5 cm difference, green 0 cm, yellow +5 cm, and red +10 cm. Figure 3 shows the same series of strips after adjustment. Because the center of the overlap zone is where adjacent strips are mosaicked via a mosaic line, it is important that these lines are consistently green. As shown in Figure 3 this is the case for all strips which results in smooth contouring across the entire project. This wouldn't have been the case using traditional methods that ignore within-strip errors associated with the GPS/IMU system.

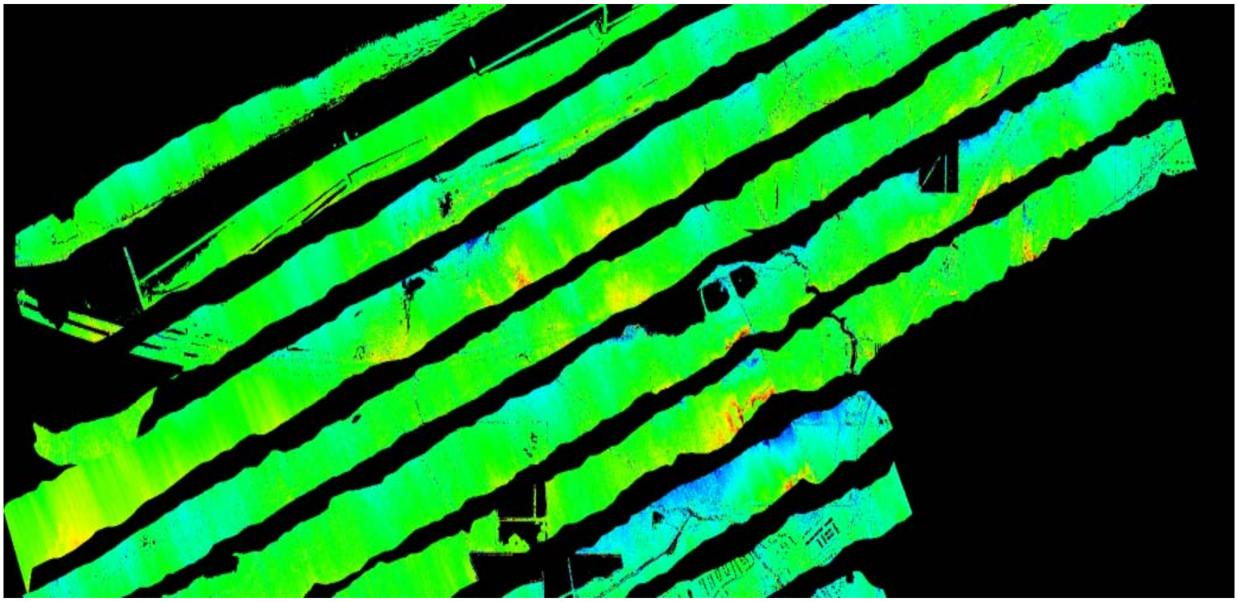


Figure 2. Overlap data prior to within-strip correction, colored by elevation difference (blue = -10 cm, cyan = -5 cm, green = 0 cm, yellow = +5cm, red = +10 cm).

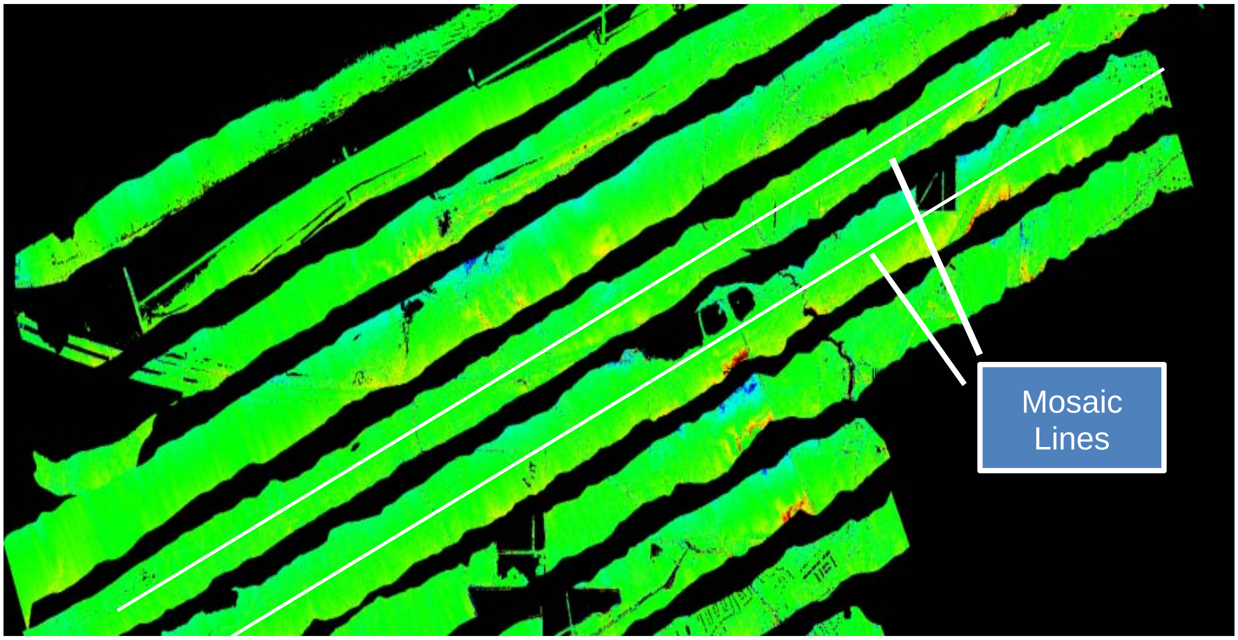


Figure 3. Overlap data after the within-strip correction, colored by elevation difference (blue = -10 cm, cyan = -5 cm, green = 0 cm, yellow = +5cm, red = +10 cm).

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.

Significant effort was given to the creation of automated routines that would detect the dozens of river banks and hundreds of lake shorelines within the subject areas. The routine then automatically creates polylines that then serve as breaklines for hydro-flattening. For this work, custom tools were developed using LAS-tools, a set of routines developed by Martin Isenburg (out of Germany), and custom Matlab scripts developed in-house. These breaklines, consisting of a series of closely spaced points were then added to the point cloud LAS files with a unique classification code. When combined in a LAS file with original lidar points, the quality of the hydro-flattening can immediately be exploited as a triangulated irregular network (TIN) in any LAS viewer or GIS system (such as ArcGIS).

Using the point classifications and breakline points, digital elevation models (DEMs) of the bare earth and digital surface models (DSMs) of all points were generated for each tile and carefully checked for data quality assurance.

Methodology

The QC 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 their 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

Relative Accuracy

Relative DEM accuracy was checked for the four typical terrain types within this project using RTK GPS surveys. Table 5 shows the results for these areas. The results show a relative accuracy of 2 cm within the Cedar City Airport runway and tarmac area. This is well under the 7.0 cm specification required by the contract. Within relatively flat sagebrush terrain, a relative accuracy of 2.8 cm was achieved and in bouldery hillsides and areas treed by cedars, a relative accuracy of 8 to 9 cm was measured. This is again within the required specifications.

Table 5. Relative accuracy checks.

Point	Area	# Points	RMSEz (cm)	Terrain Description
Q 376	Cedar Valley	23	2.8	Sagebrush in flat terrain
FAA CDC A	Cedar Valley	26	2.0	Airport runway and tarmack
H28	Cedar Valley	22	8.7	Cedar trees and rock outcrops
C 364	Hurricane Fault	24	8.2	Bouldery steep hillside

Within Swath Overlap Accuracy

Table 6 shows the mean and RMSEz difference between all DEM cells within overlapping regions. These statistics were calculated by custom Matlab scripts in USU's custom adjustment software. Table 6 shows that systematic shifts within a given overlap region are less than 1 cm. In areas of sparse vegetation, the RMSEz between overlapping surfaces is about 7.2 cm and in the forested Ogden Valley area, the RMSEz is 14.7 cm. This relatively high value is likely caused by difference in DEM interpolation under the forest canopy. This interpolation can vary due to occlusion patterns that depend on scan angle. In open areas, the RMSEz is much less than the average shown. These results are within the required specifications.

Table 6. Mean and RMSEz difference between DEM cells within overlapping regions.

Area	Number of Overlaps	Difference in Overlap (cm)	
		Mean	RMSEz
Ogden Valley	41	-0.1	14.7
Hurricane Fault	15	-0.9	7.2
Cedar Valley	197	0.5	7.3

Fundamental Vertical Accuracy

It was proposed and accepted by AGRC that a series of 5' diameter LiDAR targets be used as a spot checks for fundamental vertical accuracy relative to a selection of know brass bench marks distributed around the subject area. The strategy was to place these targets prior to the flights and measure their height using the lidar results such that they could be compared to independently leveled heights measured in the field relative to the brass bench marks. Table 7 shows the results of this work for bench marks occupied by long GPS static observations associated with the lidar collection. The results indicate an average fundamental vertical accuracy of 4.7 cm for the four targets relative to the published bench mark elevations. It should be noted that the average difference between the GPS static measurements and the published elevations is 3.5 cm. These results indicate the fundamental vertical accuracy is well within specifications required for this project.

Table 7. Fundamental vertical accuracy as determined at four lidar target locations with strong vertical control.

Target	RSMEz BM to	RSMEz BM to GPS (m)	Description
Q 376*	0.065	0.010	Sagebrush on flat terrain
H 28*	0.028	0.012	Rocky hillside with cedar trees
C 364*	0.025	0.042	Steep rocky hillsides
SPRING	0.070	0.075	Sagebrush on flat terrain
Average	0.047	0.035	

Six targets were also placed near benchmarks that were not occupied by our static GPS surveys. These differences were found to average 4.9 cm as shown in Table 8. These result suggest that adjustments of the lidar data by up to 6 cm may be necessary in order to match local datums in the various areas surveyed.

Table 8. Vertical accuracy as determined relative to benchmarks with various vertical accuracies.

Target	RSMEz BM to	Source	Published Vertical Accuracy
K 376	0.093	NGS	1st Class II 1984
Y 375	0.023	NGS	1st Class II 1984
T 375	0.057	NGS	1st Class II 1984
P 375	0.043	NGS	1st Class II 1984
MP I-15	0.040	Iron Co	uncertain
Wolf	0.039	Ogden Valley	1.4 cm 2010
Average	0.049		

Horizontal positional accuracy was not formally tested in this project and was not a specification of this contract.

Conclusions

Given results given above, the following can be concluded:

- There is a tested < 3 cm RMSEz relative accuracy,
- There is a tested < 8 cm RMSEz overlap accuracy except in forested areas where the accuracy is <15 cm due to interpolation differences caused by occlusions, and
- There is a tested < 5 cm RMSEz fundamental vertical accuracy.

FLIGHT REPORT

USU's Cessna 208B Skywagon remote sensing aircraft, N4630F, based out of Logan, Utah was utilized on this project. This aircraft was mobilized out of Logan Municipal Airport, Utah. The actual local flight times and duration of flights were controlled by weather, fuel consumption of the aircraft on the commute from Logan, Utah, and safety of flight operations in this mountainous region. This limited our flexibility in planning for times when the GNSS constellation was most favorable thereby producing the highest number of satellites visible in the best geometric configuration relative to the GNSS receivers onboard the aircraft as well as at the base station on the ground.

Ordinarily two flights were performed per day, weather permitting. Flights originated from Logan, Utah for Cedar Valley and the two Lowry Water flight. Some gaps in the data associated with the first Lowry Water flight in September were noted. A second flight was therefore planned and completed when enroute to Cedar Valley on October 24, 2011. Flights originated from Cedar City for the Cedar Valley and Hurricane Fault areas. Flight durations varied between 3 and 4 hours. At the beginning or end of most days, a calibration flight pattern was flown over either the USU campus or a part of Cedar City. This enabled the improvement of IMU to Lidar alignment which has a tendency to drift in virtually every lidar system.

Because of limitations associated with weather and impending snow, the upland areas of Cedar Valley were flown at night on October 24 & 25, 2011.

The flight dates are summarized in Table 9.

Block	Dates
Ogden Valley	23 September 2011
Lowry Water	26 September 2011
Lowry Reflight	24 October 2011
Cedar Valley	24-27 October 2011
Hurricane Fault	26 October 2011

Navigation File(s):
A listing of GPS base station files and raw flightline (LiDAR) files is given in Appendix C.

GROUND CONTROL REPORT

Introduction

Ground control was in and near the project area in support of the lidar work. This report summarizes the results.

Table 10 provides a list of coordinates for each of the 11 bench marks used in this study. The benchmarks listed with a bold font were used as static GPS stations and were occupied during the lidar flights. Stations identified with an asterisk were used as base stations for RTK surveys subsequent to the flights.

Table 10. List of benchmarks used in the five subject areas.

STATION	PID	EPOCH	LATITUDE	LONGITUDE	NAVD88
CEDAR VALLEY					
Q 376*	**HO0467**	**1991**	**37 47 54.8 (N)**	**113 03 03.3 (W)**	**1661.55**
K 376	HO0462	1984	37 53 03. (N)	113 01 55. (W)	1651.43
H 28*	**HO0210**	**1928**	**37 37 42. (N)**	**113 06 45. (W)**	**1767.26**
Y 375	HO0481	1984	37 34 36.69 (N)	113 09 40.29 (W)	1694.81
T 375	HO0490	1984	37 28 53. (N)	113 13 11. (W)	1579.63
P 375	HO0494	1984	37 24 37. (N)	113 14 07. (W)	1454.53
MP I-15	Iron Co	2002	37 57 30.51739 (N)	112 45 03.16120 (W)	1762.87
FAA CDC A*	AA3665	2007	37 41 59.03966	113 05 39.59187 (W)	1710.39
HURRICANE FAULT					
C 364*	**HO0336**	**1982**	**37 13 02. (N)**	**113 15 47. (W)**	**1043.37**
OGDEN VALLEY					
WOLF	AI5819	2002.00	41 19 58.06944(N)	111 49 13.80077(W)	1695.81
LOWRY WATER					
SPRING	**KN0377**	**1997.917**	**39 30 01.10568(N)**	**111 29 19.22566(W)**	**1770.54**

Data Collection

Using physical descriptions of benchmark locations, each of the 11 stations were occupied, some used for static GPS observations, some used for RTK data collections and all of which were used for lidar target analysis. The static observations were made with a NovAtel dual-frequency GPS receiver. RTK measurements were made with a Topcon GR-5 GNSS (including GLONASS) base/rover pair.

Data Processing and Analysis

Processing steps performed at each benchmark include ellipsoid to orthometric height conversion, horizontal time-dependent processing of point velocities for epoch adjustment, and target leveling relative to the benchmarks. Static GPS solutions are disclosed for those points occupied and lidar shot elevations have been compiled for each of the targets. A summary of these processing results is given in Tables 11 and 12.

Table 11. Ground control computations.

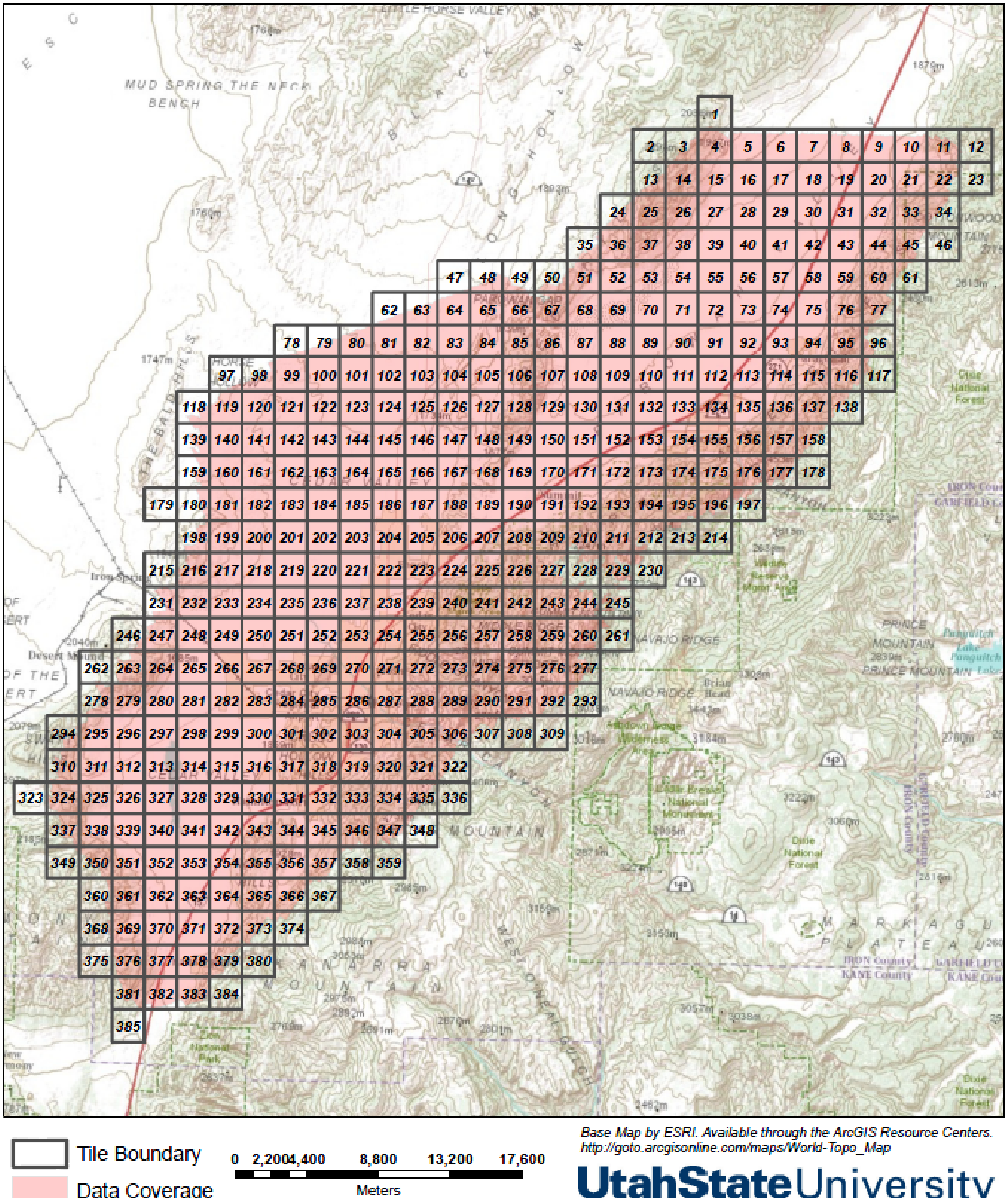
Station	NGS PID	Epoch	NAD83(HARN/1994)		NAVD88 (m)	Ellip.HT (m)	Δ (m)
			Lat	Long			
CEDAR VALLEY							
Q 376*	HO0467	1991	37 47 54.8 (N)	113 03 03.3 (W)	1661.548	1639.938	
Q 376 Adj		2011			1661.524	1639.914	
TGT Q 376		2011			1662.312	1640.702	
TGT Lidar Solutions - CV Tile 186							
Shot 1					1662.36		0.05
Shot 2					1662.38		0.07
Shot 3					1662.39		0.08
Average					1662.38		0.06
GPS CV1 Solutior		2011	37 47 54.66958(N)	113 03 03.22144(W)		1639.924	0.010
K 376	HO0462	1984	37 53 03. (N)	113 01 55. (W)	1651.429	1629.829	
K 376 Adj		2011			1651.405	1629.805	
TGT K 376		2011			1652.232	1630.632	
TGT Lidar Solutions - CV Tile 151							
Shot 1					1652.32		0.09
Shot 2					1652.33		0.10
Average					1652.33		0.09
H 28*	HO0210	1928	37 37 42. (N)	113 06 45. (W)	1767.259	1745.749	
H 28 Adj		2011			1767.235	1745.725	
TGT H 28		2011			1769.332	1747.822	
TGT Lidar Solutions - CV Tile 331							
Shot 1					1769.37		0.04
Shot 2					1769.35		0.02
Average					1769.36		0.03
GPS CV2 Solutior		2011	37 37 41.76538(N)	113 06 45.13973(W)		1745.761	0.012
Y 375	HO0481	1984	37 34 36.69 (N)	113 09 40.29 (W)	1694.807	1673.107	
Y 375 Adj		2011			1694.783	1673.083	
TGT Y 375		2011			1697.033	1675.333	
TGT Lidar Solutions - CV Tile 364							
Shot 1					1697.010		0.02
Average					1697.010		0.02
T 375	HO0490	1984	37 28 53. (N)	113 13 11. (W)	1579.626	1557.536	
T 375 Adj		2011			1579.602	1557.512	
TGT T 375		2011			1580.446	1558.356	
TGT Lidar Solutions - HF Tile 6							
Shot 1					1580.49		-0.04
Shot 2					1580.51		-0.06
Shot 3					1580.51		-0.06
Average					1580.50		-0.06
P 375	HO0494	1984	37 24 37. (N)	113 14 07. (W)	1454.533	1432.153	
P 375 Adj		2011			1454.509	1432.129	
TGT P 375		2011			1456.437	1434.057	
TGT Lidar Solutions - HF Tile 14							
Shot 1					1456.47		-0.03
Shot 2					1456.49		-0.05
Average					1456.48		-0.04

Table 12. Ground control computations (continued).

Station	NGS PID	Epoch	NAD83(HARN/1994)		NAVD88 (m)	Ellip.HT (m)	Δ (m)
			Lat	Long			
MP I-15	Iron C	2002	37 57 30.51739 (N)	112 45 03.16120 (W	1762.873	1742.35	
MP I-15 Adj		2011			1762.862	1742.342	
TGT MP I-15		2011			1763.455	1742.935	
TGT Lidar Solutions - CV Tile 31							
Shot 1					1763.470		-0.01
Shot 2					1763.520		-0.06
Average					1763.495		-0.04
FAA CDC A	AA3665	2007	37 41 59.03966	113 05 39.59187 (W	1710.39	1688.805	
CV Tile 269							
GPS FAA CDC A Solution			37.69973324	-113.0943311	1710.39	1688.805	
HURRICANE FAULT							
C 364*	HO0336	1982	37 13 02. (N)	113 15 47. (W)	1043.368	1019.938	
C 364 Adj		2011			1043.334	1019.904	
TGT		2011			1043.575	1020.145	
TGT Lidar Solution - HF Tile 37							
Shot 1					1043.54		-0.03
Shot 2					1043.55		-0.02
Shot 3					1043.56		-0.01
Average					1043.55		-0.02
GPS CV3 Solutior		2011	37 13 02.08620(N)	113 15 49.40418(W)		1019.504	-0.042
OGDEN VALLEY							
WOLF	AI5819	2002.00	41 19 58.06944(N)	111 49 13.80077(W)	1695.806	1679.936	
GPS WOLF					1697.886	1682.016	
TGT WOLF					1696.684	1680.814	
TGT Lidar Solutions							
Shot 1					1696.67		-0.01
Shot 2					1696.62		-0.06
Shot 3					1696.62		-0.06
Shot 4					1696.67		-0.01
Average					1696.65		-0.04
LOWRY WATER							
SPRING	KN0377	1997.916667	39 30 01.10568(N)	111 29 19.22566(W)	1770.540	1753.410	
		2010.00			1770.525	1753.395	
TGT		2010			1771.27		
TGT Lidar Solution (average for 2 shots)					1771.34	1754.21	0.07
GPS SPRING Solution					1770.60	1753.47	0.08

APPENDIX A – Index Maps and Area Boundaries

Cedar Valley



Base Map by ESRI. Available through the ArcGIS Resource Centers. http://goto.arcgisonline.com/maps/World-Topo_Map

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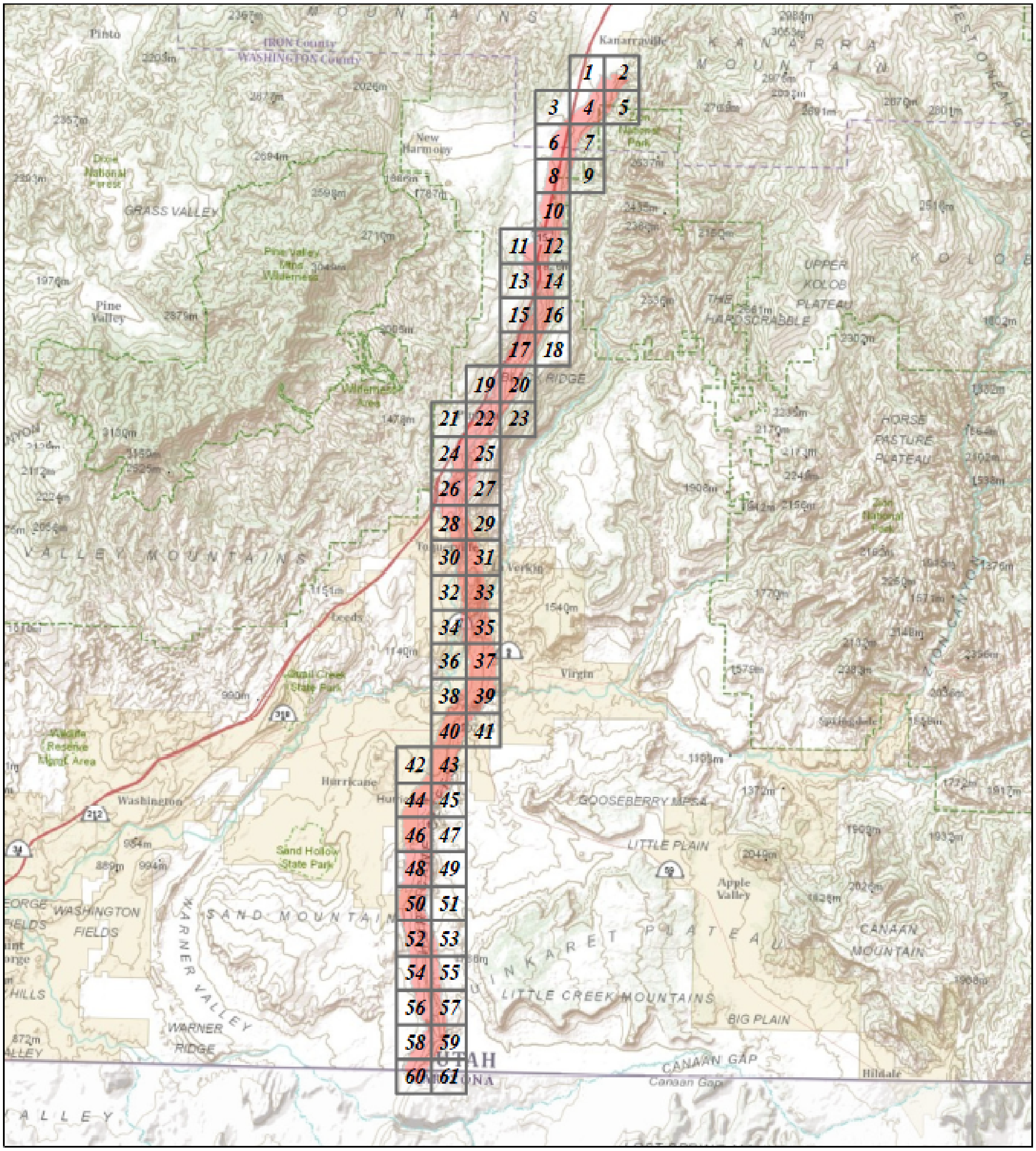
Hurricane Fault



Tile Boundary

Data Coverage

0 2,150 4,300 8,600 12,900 17,200

Meters

Base Map by ESRI. Available through the ArcGIS Resource Centers. http://goto.arcgisonline.com/maps/World-Topo_Map

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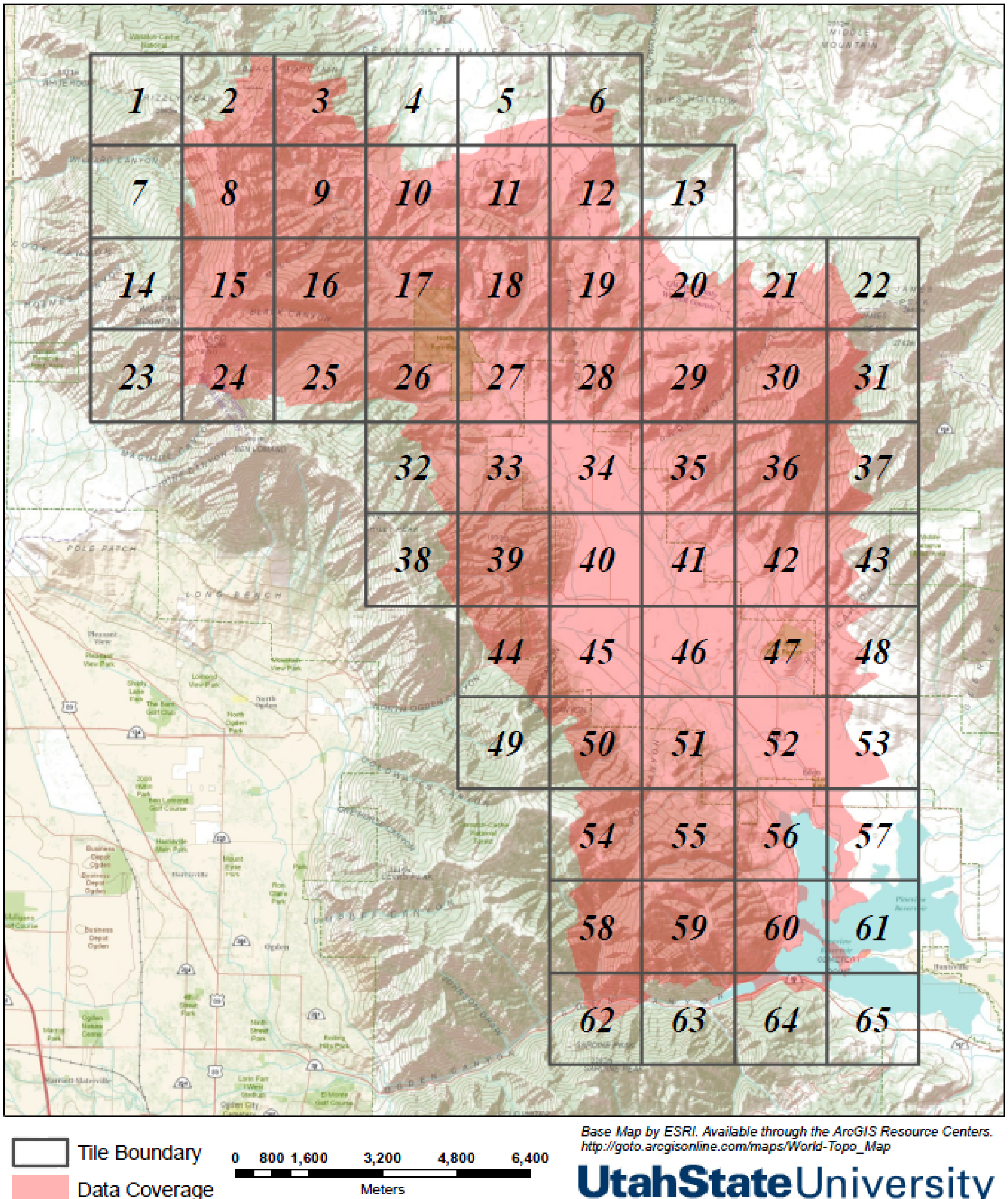
Ogden Valley



Base Map by ESRI. Available through the ArcGIS Resource Centers.
http://goto.arcgisonline.com/maps/World-Topo_Map

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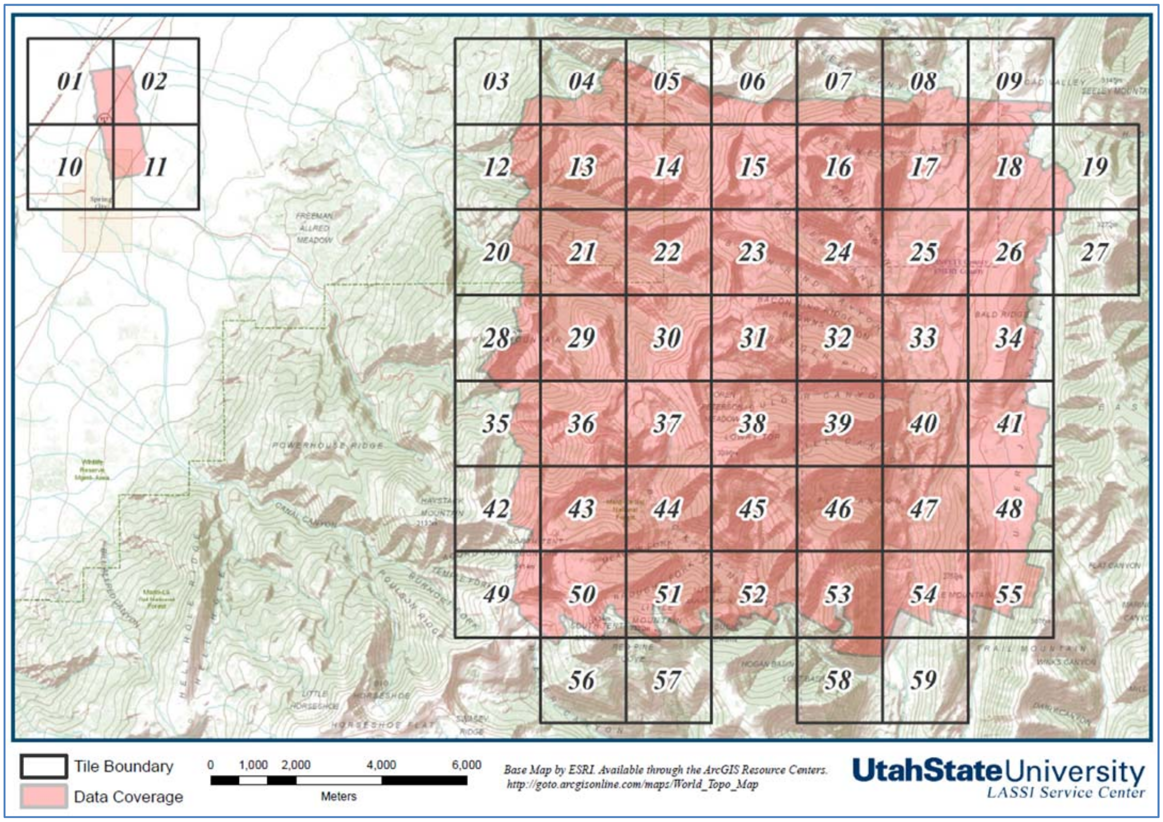
Lowry Water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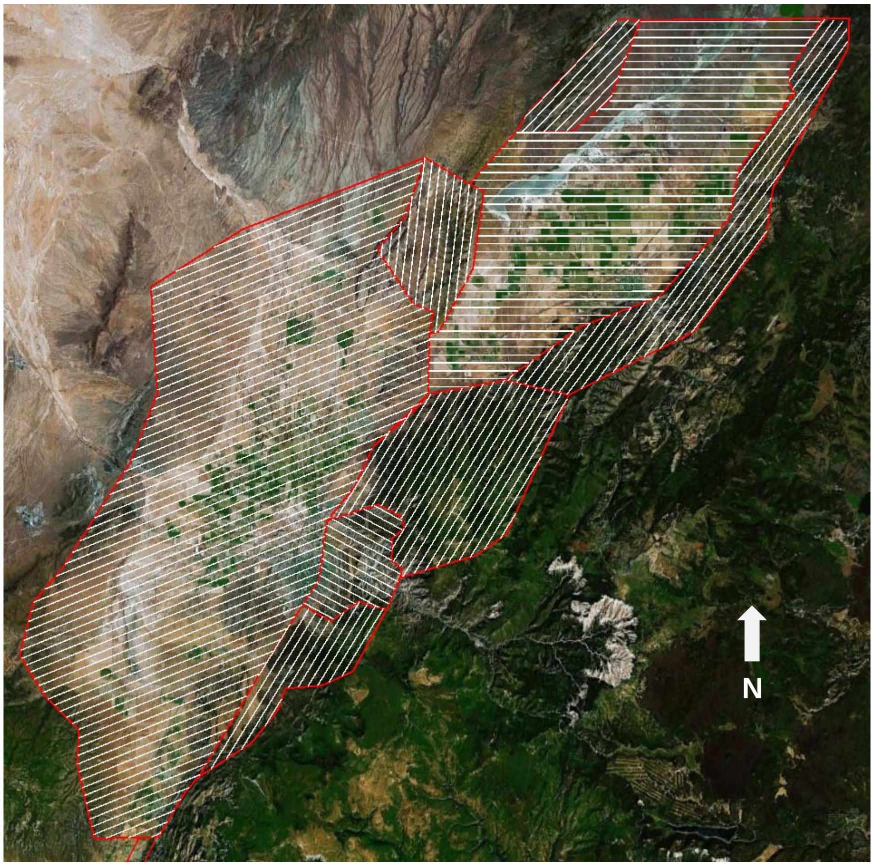
Tile Boundary
Data Coverage
0 1,000 2,000 4,000 6,000
Meters
Base Map by ESRI. Available through the ArcGIS Resource Centers.
http://goto.arcgisonline.com/maps/World_Topo_Map
UtahStateUniversity
LASSI Service Center

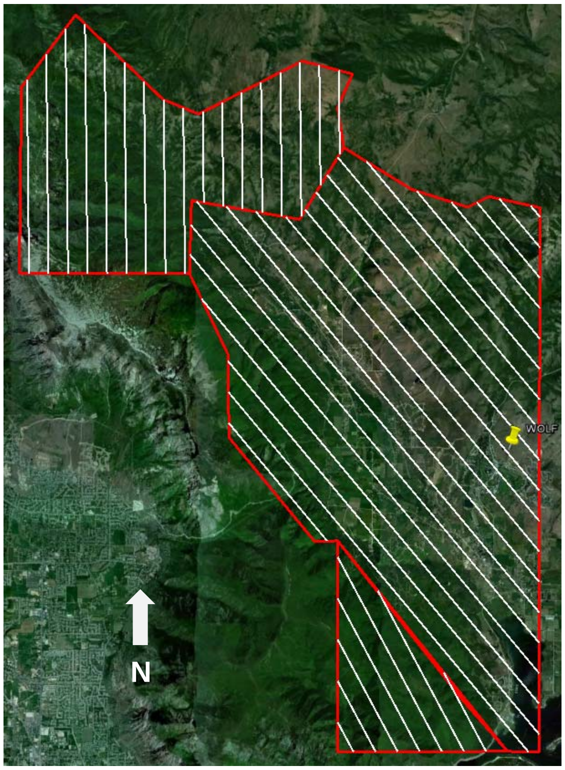
APPENDIX B – Flight Plan Maps

Cedar Valley

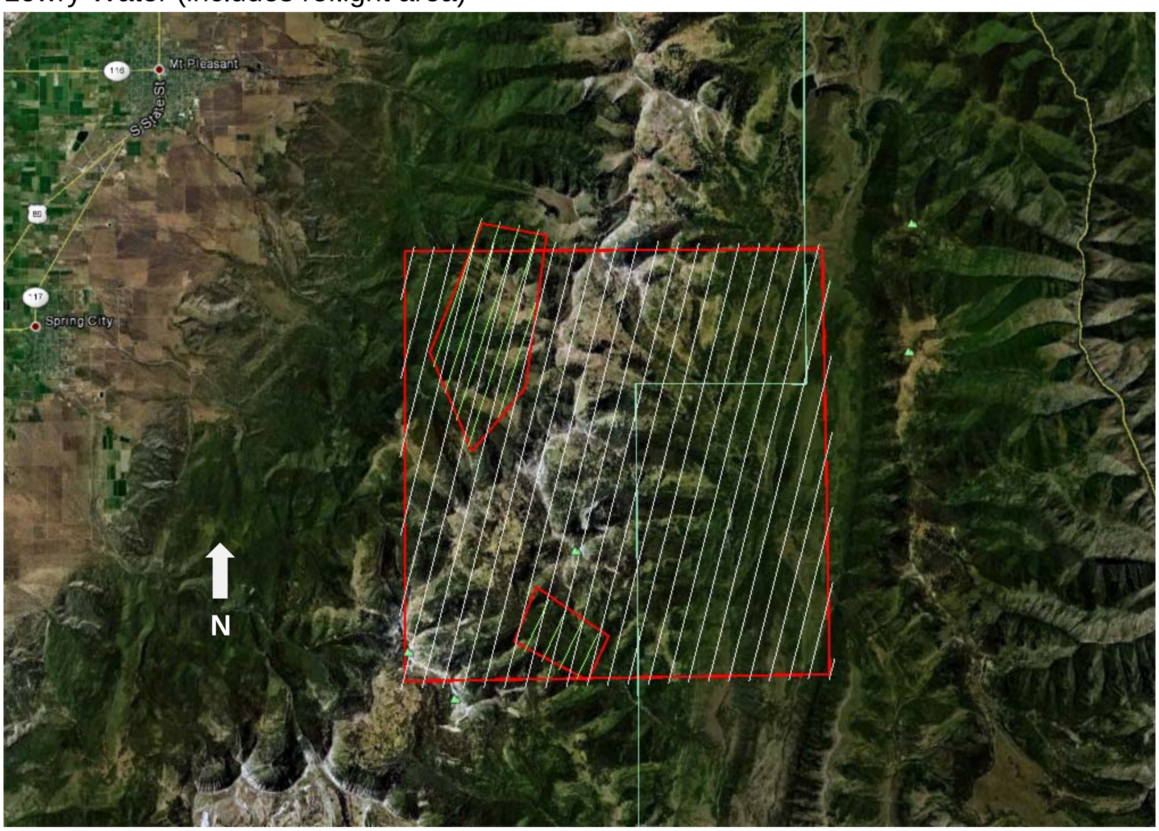


Hurricane Fault

Ogden Valley



Lowry Water (includes reflight area)



APPENDIX C – Raw Data File Listing

Cedar Valley Project: File Listing
Flown: 10/24/2011-10/27/2011

Navigation File(s):

Remote_CedarVAlley_20111024_01
Remote_CedarValley_20111024_02
Remote_CedarValley_20111025_01
Remote_CedarValley_20111025_02
Remote_CedarValley_20111026
Remote_CedarValley_20111027_01
Remote_CedarValley_20111027_02

Base Station File(s):

00052950.pdc
00052951.pdc
00052960.pdc
00052961.pdc
00052980.pdc
00052981.pdc
00052950.pdc
00052951.pdc
00052960.pdc
00052961.pdc
00052990.pdc
00052991.pdc
00052992.pdc
00052993.pdc

Raw Flightline (LIDAR) File(s):

111024_204440.sdf
111024_204950.sdf
111024_205551.sdf
111024_210058.sdf
111024_210427.sdf
111024_210802.sdf
111024_211347.sdf
111024_211822.sdf
111024_212319.sdf
111024_212828.sdf
111024_213439.sdf
111024_213625.sdf
111024_214503.sdf
111024_215019.sdf
111024_215835.sdf
111024_220218.sdf
111024_220611.sdf
111024_220933.sdf
111024_221309.sdf
111024_221613.sdf
111024_221854.sdf
111024_222103.sdf
111024_222824.sdf
111024_223102.sdf
111024_224101.sdf
111024_224626.sdf
111024_225201.sdf
111024_225746.sdf
111024_230404.sdf
111025_011508.sdf
111025_012212.sdf
111025_012811.sdf
111025_013449.sdf
111025_014015.sdf
111025_014538.sdf
111025_015005.sdf
111025_015453.sdf
111025_015933.sdf
111025_020350.sdf
111025_020809.sdf
111025_021240.sdf
111025_022132.sdf
111025_022330.sdf
111025_022614.sdf
111025_022846.sdf
111025_023145.sdf
111025_023435.sdf
111025_023730.sdf
111025_161936.sdf
111025_162316.sdf
111025_162652.sdf
111025_163032.sdf
111025_163357.sdf
111025_163743.sdf
111025_164108.sdf
111025_164420.sdf
111025_164728.sdf
111025_165041.sdf
111025_165705.sdf
111025_170016.sdf
111025_170331.sdf
111025_170725.sdf
111025_171125.sdf
111025_171558.sdf
111025_171903.sdf
111025_172020.sdf
111025_172539.sdf
111025_173212.sdf
111025_173731.sdf
111025_174635.sdf
111025_175031.sdf
111025_175458.sdf
111025_180011.sdf
111025_180520.sdf
111025_181011.sdf
111025_181445.sdf
111025_181920.sdf
111025_182348.sdf

111025_182741.sdf
111025_183024.sdf
111025_183300.sdf
111025_184216.sdf
111025_184655.sdf
111025_185129.sdf
111025_185626.sdf
111025_190057.sdf
111025_190453.sdf
111025_190825.sdf
111025_211820.sdf
111025_211955.sdf
111025_212141.sdf
111025_213537.sdf
111025_214022.sdf
111025_214553.sdf
111025_215032.sdf
111025_215619.sdf
111025_220059.sdf
111025_220635.sdf
111025_221100.sdf
111025_221625.sdf
111025_222111.sdf
111025_222628.sdf
111025_223108.sdf
111025_223628.sdf
111025_224936.sdf
111025_225426.sdf
111025_230138.sdf
111025_230727.sdf
111025_231427.sdf
111025_232009.sdf
111025_232658.sdf
111025_233255.sdf
111025_233939.sdf
111025_234546.sdf
111026_000324.sdf
111026_000941.sdf
111026_001541.sdf
111026_002156.sdf
111026_002742.sdf
111026_003403.sdf
111026_003940.sdf
111026_004514.sdf
111026_005041.sdf
111026_005612.sdf
111026_010135.sdf
111026_010654.sdf
111026_011211.sdf
111026_214818.sdf
111026_215015.sdf
111026_215240.sdf
111026_215556.sdf
111026_215926.sdf
111026_220330.sdf
111026_220725.sdf
111026_221120.sdf
111026_221945.sdf
111026_222351.sdf
111026_222811.sdf
111026_223252.sdf
111026_223801.sdf
111026_225551.sdf
111026_230102.sdf
111026_230601.sdf
111026_231118.sdf
111026_231628.sdf
111026_232141.sdf
111026_232700.sdf
111026_233253.sdf
111026_233851.sdf
111026_234532.sdf
111026_235137.sdf
111026_235848.sdf
111027_000529.sdf
111027_001339.sdf
111027_001512.sdf
111027_001707.sdf
111027_001951.sdf
111027_002117.sdf
111027_002535.sdf
111027_002802.sdf
111027_003507.sdf
111027_004242.sdf
111027_005020.sdf
111027_005825.sdf
111027_010557.sdf
111027_011408.sdf
111027_012130.sdf
111027_012959.sdf
111027_013805.sdf
111027_170640.sdf
111027_170832.sdf
111027_171055.sdf
111027_171343.sdf
111027_172249.sdf
111027_173105.sdf
111027_173912.sdf
111027_174718.sdf
111027_175547.sdf
111027_180401.sdf
111027_181230.sdf
111027_182033.sdf
111027_182833.sdf
111027_183620.sdf
111027_184402.sdf
111027_185123.sdf
111027_185846.sdf
111027_190559.sdf
111027_191357.sdf
111027_192051.sdf
111027_192748.sdf
111027_193412.sdf
111027_194026.sdf
111027_194643.sdf
111027_195246.sdf
111027_195846.sdf
111027_200453.sdf
111027_201104.sdf
111027_201706.sdf
111027_202308.sdf
111027_202924.sdf
111027_203554.sdf
111027_204242.sdf
111027_204911.sdf
111027_205611.sdf
111027_210232.sdf
111027_210940.sdf
111027_221650.sdf
111027_222613.sdf
111027_223056.sdf
111027_223517.sdf
111027_223930.sdf
111027_224319.sdf
111027_224708.sdf
111027_225035.sdf
111027_225412.sdf
111027_225717.sdf

111027_230020.sdf	111028_001715.sdf	111028_012138.sdf
111027_230720.sdf	111028_002055.sdf	111028_012747.sdf
111027_231231.sdf	111028_002455.sdf	111028_013401.sdf
111027_231818.sdf	111028_002815.sdf	111028_013925.sdf
111027_232331.sdf	111028_003155.sdf	111028_014541.sdf
111027_232644.sdf	111028_003445.sdf	111028_015116.sdf
111027_232945.sdf	111028_003758.sdf	111028_015556.sdf
111027_233408.sdf	111028_003951.sdf	111028_020030.sdf
111027_234145.sdf	111028_004616.sdf	111028_020449.sdf
111027_234836.sdf	111028_004841.sdf	111028_020913.sdf
111027_235400.sdf	111028_005314.sdf	111028_021326.sdf
111027_235841.sdf	111028_005834.sdf	111028_021804.sdf
111028_000351.sdf	111028_010407.sdf	111028_022155.sdf
111028_000946.sdf	111028_010953.sdf	
111028_001325.sdf	111028_011537.sdf	

Ogden Valley Project: File Listing

Flown: 9/23/2011

Navigation File(s):

Remote_OgdenValley_20110923_01 Remote_20110923_02

Base Station File(s):

BaseStation_20110923.pdc

Raw Flightline (LIDAR) File(s):

110923_162924.sdf	110923_174926.sdf	110923_212628.sdf
110923_163033.sdf	110923_175417.sdf	110923_213014.sdf
110923_163251.sdf	110923_175910.sdf	110923_213352.sdf
110923_163836.sdf	110923_180348.sdf	110923_213745.sdf
110923_164128.sdf	110923_180809.sdf	110923_214735.sdf
110923_164455.sdf	110923_181436.sdf	110923_215053.sdf
110923_164900.sdf	110923_181843.sdf	110923_215353.sdf
110923_165224.sdf	110923_182213.sdf	110923_215700.sdf
110923_165700.sdf	110923_182508.sdf	110923_215948.sdf
110923_165947.sdf	110923_182806.sdf	110923_220158.sdf
110923_170538.sdf	110923_183015.sdf	110923_220414.sdf
110923_171154.sdf	110923_183233.sdf	110923_220646.sdf
110923_171813.sdf	110923_184404.sdf	110923_220910.sdf
110923_172445.sdf	110923_184611.sdf	110923_221158.sdf
110923_173127.sdf	110923_184912.sdf	110923_221443.sdf
110923_173731.sdf	110923_211901.sdf	110923_221749.sdf
110923_174354.sdf	110923_212303.sdf	

Hurricane Project: File Listing
Flown: 10/26/2011

Navigation File(s):

Remote_HurricaneFault_20111026

Base Station File(s):

00052990.pdc
00052991.pdc
00052992.pdc

Raw Flightline (LIDAR) File(s):

111026_183901.sdf
111026_184840.sdf
111026_185709.sdf
111026_190343.sdf
111026_191721.sdf
111026_193443.sdf
111026_194315.sdf
111026_195240.sdf

Lowry Project: File Listing
Flown: 9/26/2011 & 10/24/2011

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