WOOLPERT

Lower Colorado River Multi-Species Conservation Program (MSCP), AZ-CA Lidar and Ortho Imagery

Lidar Processing Report

United States Geological Survey

July 2015

Table of Contents

List of Figures

List of Tables

Section 1: Overview

Project Name: Lower Colorado River Multi-Species Conservation Program (MSCP), AZ-CA Lidar and Ortho Imagery

Woolpert Project: #75433

This report contains a comprehensive outline of the Lower Colorado River Multi-Species Conservation Program (MSCP), AZ-CA Lidar and Ortho Imagery task order. This task is issued under USGS Contract Number: G10PC00057, and Task Order Number: 15PD00283. This task order requires lidar data to be acquired over the Lower Colorado River in Arizona and California beginning at the Imperial Dam and ending approximately 11 miles downstream at the Laguna Dam. The total area of the AOI is approximately 21 square miles. The lidar was collected and processed to meet a maximum Nominal Post Spacing (NPS) of 0.5 meter. The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.

The data was collected using an Optech Gemini Multiple Pulses in Air (MPiA) lidar sensor. The Gemini sensor collects up to four returns per pulse, as well as intensity data, for the first three returns. If a fourth return was captured, the system does not record an associated intensity value. The aerial lidar was collected at the following sensor specifications:

Table 1.1: Optech Gemini Acquisition Specifications	
Post Spacing	1.6 ft / 0 .5 m
AGL (Above Ground Level) average flying height	1,968 ft / 600 m
MSL (Mean Sea Level) average flying height	2,132 ft / 650 m
Average Ground Speed:	110 knots / 126 mph
Field of View (full)	24 degrees
Pulse Rate	70 kHz
Scan Rate	61.6 Hz
Side Lap	30%

The lidar data was processed and projected in UTM, Zone 11, North American Datum of 1927 in units of survey feet. The vertical datum used for the task order was referenced to NGVD 29, in units of survey feet.

A second lidar dataset was projected and delivered in UTM, Zone 11, North American Datum of 1983 (2011) in units of meters. The vertical datum used for the task order was referenced to NAVD88 (GEOID12A), in units of meters.

Figure 1.1: Lidar Task Order AOI

Section 2: Acquisition

The existing lidar data was acquired with an Optech Gemini Multiple Pulses in Air (MPiA) Lidar Sensor System, on board a fixed-wing Cessna aircraft. The Optech Gemini lidar system, developed by Optech of Canada, includes the simultaneous first, intermediate and last pulse data capture module. The system software is operated by ALTM-NAV aboard the aircraft. Keystone Aerial Surveys Inc. of Philadelphia, PA was contracted to acquire the Lidar data.

The Optech Gemini Multiple Pulses in Air (MPiA) Lidar System has the following specifications:

Table 2.1: Optech Gemini Lidar System Specification	
Operating Altitude	150 – 4,000 meters
Scan Angle	0 to 50° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 70 Hz (variable based on scan angle)
Maximum Pulse Rate	167 kHz (Effective)
Range Resolution	Better than 1 cm
Elevation Accuracy	5 - 35 cm single shot (one standard deviation)
Horizontal Accuracy	1/5,500 x altitude (m AGL)
Number of Returns per Pulse	4 (first, second, third, last)
Number of Intensities	3 (first, second, third)
Intensity Digitization	12 bit dynamic measurement range
MPiA (Multiple Pulses in Air)	8 bits @ 1nsec interval @ 50kHz
Laser Beam Divergence	Dual Divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e) nominal
Laser Classification	Class IV laser product (FDA CFR 21)
Eye Safe Range	400m single shot depending on laser repetition rate
Roll Compensation	+/- 5 degrees at full FOV
Power Requirements	28 VDC @ 25A
Operating Temperature	0-40°C
Humidity	0-95% non-condensing
Supported GNSS Receivers	Ashtech Z12, Trimble 7400, Novatel Millenium

Prior to mobilizing to the project site, flight crews coordinated with the necessary Air Traffic Control personnel to ensure airspace access.

Survey crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Station for the airborne GPS support.

The lidar data was collected in one (1) mission. An initial quality control process was performed immediately on the lidar data to review the data coverage, airborne GPS data, and trajectory solution. Any gaps found in the lidar data were relayed to the flight crew, and the area was re-flown.

Figure 2.1: Lidar Flight Layout, Lower Colorado River MSCP

Table 2.2: Airborne Lidar Acquisition Flight Summary

Date of Mission	Lines Flown	Mission Time (UTC) Wheels Up/ Wheels Down	Mission Time (Local = EDT) Wheels Up/ Wheels Down
April 18, 2015	1-35	16:55 – 21:11	8:55 AM – 01:11 PM

Section 3: Lidar Data Processing

Applications and Work Flow Overview

1. Applanix version 7.1 was used to create airborne solution files (SBET/accuracy files).
2. Optech's LiDAR Mapping Suite (LMS) version 2.4.1.15653 was used to create the .LAS files and for relative adjustments and corrections. Adjustments were made based on corrections between overlapping tie-planes.
3. Terrasolid's TerraScan/TerraMatch were used to manually inspect the LMS automated relative corrections. An additional individual line solution was created an applied to all flight lines for a correction of roll and z (see TMATCH files on FTP). One the relative accuracy was verified the LiDAR data was shifted to the (BOR) provided ground control using a TerraScan native transformation macro.
4. Imported processed LAS point cloud data into the task order tiles. Resulting data were classified as ground and non-ground points with additional filters created to meet the task order classification specifications. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Software: TerraScan v.15.011.
5. Imported processed LAS point cloud data into the task order tiles. Resulting data were classified as ground and non-ground points with additional filters created to meet the task order classification specifications. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Based on the statistical analysis, the lidar data was then adjusted to reduce the vertical bias when compared to the survey ground control .Software: TerraScan v.15.011.
6. Imported processed LAS point cloud data into the task order tiles. Resulting data were classified as ground and non-ground points with additional filters created to meet the task order classification specifications. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Based on the statistical analysis, the lidar data was then adjusted to reduce the vertical bias when compared to the survey ground control. Software: TerraScan v.15.011.
7. The LAS files were evaluated through a series of manual QA/QC steps to eliminate remaining artifacts from the ground class. Software: TerraScan v.15.011.

Global Navigation Satellite System (GNSS) – Inertial Measurement Unit (IMU) Trajectory Processing

Equipment

Flight navigation during the lidar data acquisition mission is performed using Optech's ALTM Navigation System. The pilots are skilled at maintaining their planned trajectory, while holding the aircraft steady and level. If atmospheric conditions are such that the trajectory, ground speed, roll, pitch and/or heading cannot be properly maintained, the mission is aborted until suitable conditions occur.

A base-station unit was mobilized for the acquisition, and was operated by a member of the acquisition team. The base-station setup consisted of a Novatel 702GG dual-frequency GPS+GLONASS pinwheel antenna The GNSS base station operated during the Lidar acquisition mission is listed below:

Table 3.1: GNSS Base Station

Station (Name)	Latitude (DMS)	Longitude (DMS)	Ellipsoid Height (L1 Phase center) (Meters)
KNYL Base	32°39' 46.13056"	-114°36' 30.50171"	57.892

Data Processing

All airborne GNSS and IMU data was post-processed and quality controlled using Applanix MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

Trajectory Quality

The GNSS Trajectory, along with high quality IMU data are key factors in determining the overall positional accuracy of the final sensor data. Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

The Combined Separation is a measure of the difference between the forward run and the backward run solution of the trajectory. The Kalman filter is processed in both directions to remove the combined directional anomalies. In general, when these two solutions match closely, an optimally accurate reliable solution is achieved.

Woolpert's goal is to maintain a Combined Separation Difference of less than ten (10) centimeters. In most cases we achieve results below this threshold.

The Estimated Positional Accuracy plots the standard deviations of the east, north, and vertical directions along a time scale of the trajectory. It illustrates loss of satellite lock issues, as well as issues arising from long baselines, noise, and/or other atmospheric interference.

Woolpert's goal is to maintain an Estimated Positional Accuracy of less than ten (10) centimeters, often achieving results well below this threshold.

The PDOP measures the precision of the GPS solution in regards to the geometry of the satellites acquired and used for the solution. Woolpert's goal is to maintain an average PDOP value below 3.0. Brief periods of PDOP over 3.0 are acceptable due to the calibration and control process if other metrics are within specification.

Lidar Data Processing

When the sensor calibration, data acquisition, and GPS processing phases were complete, the formal data reduction processes by Woolpert lidar specialists included:

- Calibrated LAS files were imported into the task order tiles and initially filtered to create a ground and non-ground class. Then additional classes were filtered as necessary to meet client specified classes.
- Once all project data was imported and classified, survey ground control data was imported and calculated for an accuracy assessment. As a QC measure, Woolpert has developed a routine to generate accuracy statistical reports by comparisons against the TIN and the DEM using surveyed ground control of higher accuracy. The lidar is adjusted accordingly to meet or exceed the vertical accuracy requirements.
- The lidar tiles were reviewed using a series of proprietary QA/QC procedures to ensure it fulfills the task order requirements. A portion of this requires a manual step to ensure anomalies have been removed from the ground class.
- The lidar LAS files are classified into the Default (Class 1), Ground (Class 2), Low Vegetation (Class 3), Medium Vegetation

(Class 4), High Vegetation (Class 5) Buildings (Class 6), Noise (Class 7), Water (Class 9), Ignored Ground (Class 10), Overlap default (Class 17), and Overlap Ground (Class 18) classifications.

- FGDC Compliant metadata was developed for the task order per delivery projection in .xml format for the final data products.
- The horizontal datum used for the task order was referenced to UTM, Zone 11, North American Datum of 1927). The vertical datum used for the task order was referenced to NGVD 29. Coordinate positions were specified in units of survey feet.
- A second data set was referenced to UTM, Zone 11, North American Datum of 1983 (2011). The vertical datum used was NAVD88 (GEOID12A). Coordinate positions were specified in units of meters.

Section 4: Hydrographic Flattening

HYDROLOGIC FLATTENING OF LIDAR DEM DATA

Lower Colorado River MSCP Lidar Processing task order required the compilation of breaklines defining water bodies and rivers. The breaklines were used to perform the hydrologic flattening of water bodies, and gradient hydrologic flattening of double line streams and rivers. Lakes, reservoirs and ponds, at a minimum size of 2-acre or greater, were compiled as closed polygons. The closed water bodies were collected at a constant elevation. Rivers and streams, at a nominal minimum width of 30 meters (100 feet), were compiled in the direction of flow with both sides of the stream maintaining an equal gradient elevation.

LIDAR DATA REVIEW AND PROCESSING

Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing lidar data.

1. Woolpert used the newly acquired lidar data to manually draw the hydrologic features in a 2D environment using the lidar intensity and bare earth surface. Open Source imagery was used as reference when necessary.
2. Woolpert utilizes an integrated software approach to combine the lidar data and 2D breaklines. This process “drapes” the 2D breaklines onto the 3D lidar surface model to assign an elevation. A monotonic process is performed to ensure the streams are consistently flowing in a gradient manner. A secondary step within the program verifies an equally matching elevation of both stream edges. The breaklines that characterize the closed water bodies are draped onto the 3D lidar surface and assigned a constant elevation at or just below ground elevation.
3. The lakes, reservoirs and ponds, at a minimum size of 2-acre or greater and streams at a minimum size of 30 meters (100 feet) nominal width, were compiled to meet task order requirements. **Figure 4.1** illustrates an example of 30 meters (100 feet) nominal streams identified and defined with hydrologic breaklines. The breaklines defining rivers and streams, at a nominal minimum width of 30 meters (100 feet), were draped with both sides of the stream maintaining an equal gradient elevation.
4. All ground points were reclassified from inside the hydrologic feature polygons to water, class nine (9).
5. All ground points were reclassified from within a buffer along the hydrologic feature breaklines to buffered ground, class ten (10).
6. The lidar ground points and hydrologic feature breaklines were used to generate a new digital elevation model (DEM).

Figure 4.1: Example Hydrologic Breaklines

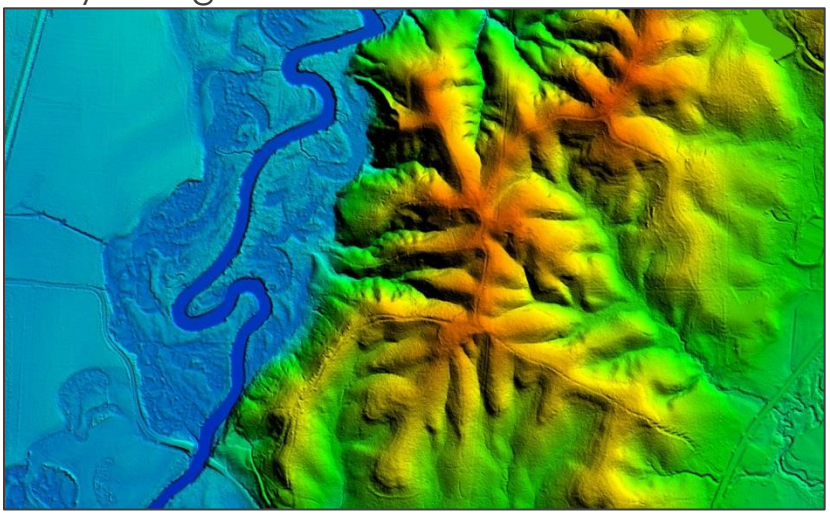

Figure 4.2 reflects a DEM generated from original lidar bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

Figure 4.3 reflects a DEM generated from lidar with breaklines compiled to define the hydrologic features. This figure illustrates the results of adding the breaklines to hydrologically flatten the DEM data. Note the smooth appearance of the lake surface in the DEM.

Figure 4.2

Figure 4.3

Terrascan was used to add the hydrologic breakline vertices and export the lattice models. The hydrologically flattened DEM data was provided to USGS in ESRI grid format at a 2 foot cell size.

The hydrologic breaklines compiled as part of the flattening process were provided to the USGS as an ESRI Geodatabase. The breaklines defining the water bodies greater than 1-acre and for the gradient flattening of all rivers and streams at a nominal minimum width of 15 meters (50 feet) were provided as a Polygon-Z feature class.

DATA QA/QC

Initial QA/QC for this task order was performed in Global Mapper v15, by reviewing the grids and hydrologic breakline features. Additionally, ESRI software and proprietary methods were used to review the overall connectivity of the hydrologic breaklines.

Edits and corrections were addressed individually by tile. If a water body breakline needed to be adjusted to improve the flattening of the DEM data, the area was cross referenced by tile number, corrected accordingly, a new DEM file was regenerated and reviewed.

Section 5: ACCURACY ASSESSMENT

Accuracy Assessment NAD27 Delivery

The vertical accuracy statistics were calculated by comparison of the lidar bare earth points to the ground surveyed QA/QC points.

Table 5.1: Overall Vertical Accuracy Statistics, NAD27		
Average error	-0.053	feet
Minimum error	-0.244	feet
Maximum error	0.401	feet
Average magnitude	0.121	feet
Root mean square	0.150	feet
Standard deviation	0.144	feet

Table 5.2: Raw Swath Quality Check Point Analysis FVA, NAD27

Point ID	Easting (feet)	Northing (feet)	Laser Elevation (feet)	Dz (feet)
2001	2409115.552	11925870.863	161.860	0.052
2002	2411416.075	11927950.747	158.370	-0.030
2003	2410757.901	11936600.376	168.380	-0.078
2004	2415613.906	11940833.393	163.640	-0.065
2005	2416216.749	11944283.292	188.690	-0.107
2006	2420372.481	11945457.598	197.630	0.023
2007	2420717.673	11941826.842	161.720	0.119
2008	2423929.893	11938579.714	186.130	-0.218
2009	2425117.616	11935194.948	184.670	-0.024
2010	2426897.296	11929587.247	185.320	-0.244
2011	2420912.071	11920966.150	184.550	0.401
2012	2416038.675	11921349.028	158.410	0.025
2013	2413133.570	11924037.861	160.080	-0.075
2014	2415364.659	11936100.435	159.690	-0.135
2015	2413495.536	11936365.904	161.070	0.127
2016	2416239.478	11938062.849	164.710	-0.096
2017	2416910.880	11940714.021	164.410	-0.099
2018	2417029.713	11941885.861	167.220	-0.147
2019	2420610.994	11939658.699	161.290	-0.137
2020	2424146.041	11937204.433	183.410	-0.048
2021	2421101.408	11943576.340	184.760	-0.181
2022	2410455.851	11933110.005	159.030	-0.231

VERTICAL ACCURACY CONCLUSIONS

Raw LAS Swath Fundamental Vertical Accuracy (FVA) Tested 0.088 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using 0.045 meters (RMSEz) x 1.96000 as defined by the National Standards for

Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using all points.

LAS Swath Fundamental Vertical Accuracy (FVA) Tested 0.105 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using 0.054(RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using just ground points.

Bare-Earth DEM Fundamental Vertical Accuracy (FVA) Tested 0.096 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using 0.049 meters (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM.

SUPPLEMENTAL VERTICAL ACCURACY ASSESSMENTS

Table 5.3: Tall Weeds and Crops Quality Check Point Analysis SVA, NAD27

Point ID	Easting (feet)	Northing (feet)	DEM Elevation (feet)	Dz (feet)
4001	2409200.320	11925817.220	161.670	-0.279
4002	2411411.224	11927904.798	157.370	-0.049
4003	2410914.055	11936586.431	169.410	-0.205
4004	2415608.421	11940690.108	163.140	0.176
4005	2417531.566	11945964.501	187.440	-0.053
4006	2420502.206	11945316.618	198.770	-0.555
4007	2420872.145	11941739.277	161.240	0.266
4008	2424052.922	11938726.200	182.250	-0.043
4009	2425140.118	11934851.740	177.340	-0.092
4010	2426977.505	11929625.970	178.700	-0.195
4011	2421219.605	11920906.998	164.760	-0.137
4012	2416758.804	11921495.761	177.540	0.009
4013	2413246.675	11924089.906	157.640	0.251
4014	2415070.432	11936051.530	181.670	-0.07
4015	2413397.899	11936457.201	163.400	0.279
4016	2416264.044	11938131.677	165.540	0.299
4017	2416828.252	11940699.509	164.220	-0.19
4018	2417009.448	11941747.507	167.920	-0.032
4019	2420716.641	11939695.804	162.240	0.074
4020	2423779.669	11937509.579	170.800	-0.28
4021	2421013.862	11943631.178	180.780	0.193
4022	2410177.921	11933621.354	160.200	-0.219

VERTICAL ACCURACY CONCLUSIONS

Tall Weeds and Crops Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.091 meters supplemental vertical accuracy at the 95th percentile in the Tall Weeds and Crops supplemental class reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM. Tall Weeds and Crops Errors larger than 95th percentile include:

- Point 4006, Easting 2420502.206, Northing 11945316.618, Z-Error 0.169 meter

Table 5.4: Brushlands and Trees Quality Check Point Analysis SVA, NAD27

Point ID	Easting (feet)	Northing (feet)	DEM Elevation (feet)	Dz (feet)
5001	2409173.876	11925784.780	161.020	0.050
5002	2411374.182	11928063.064	156.620	-0.043
5003	2411224.142	11936797.906	164.200	0.036
5004	2415663.609	11940967.912	161.140	-0.016
5005	2417382.771	11945920.910	187.210	-0.226
5006	2419407.940	11944926.159	171.420	-0.079
5007	2420156.449	11941658.812	163.220	0.029
5008	2424083.720	11938918.078	182.300	-0.143
5009	2425088.337	11934912.796	175.790	-0.229
5010	2427046.804	11929859.349	179.590	0.288
5011	2421125.355	11921053.806	164.640	-0.052
5012	2415867.094	11921130.545	158.770	0.275
5013	2413337.338	11924214.488	159.090	0.006
5014	2415266.014	11936001.471	157.540	0.474
5015	2413465.969	11936212.042	162.770	0.309
5016	2416178.136	11938185.185	163.020	-0.059
5017	2416862.537	11940871.905	162.810	-0.043
5018	2416973.721	11941855.466	167.410	0.282
5019	2420741.829	11939508.060	161.230	0.332
5020	2424217.158	11937301.405	184.350	0.010
5021	2420967.476	11943640.168	170.660	-0.128
5022	2410453.336	11933447.685	158.490	-0.123

VERTICAL ACCURACY CONCLUSIONS

Brushlands/Trees Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.103 meters supplemental vertical accuracy at the 95th percentile in the Tall Weeds/Crops supplemental class reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM. Brushlands/Trees Errors at the 95th percentile include:

- Point 5014, Easting 2415266.014, Northing 11936001.471, Z-Error 0.144 meters

Table 5.5: Swamp/Marsh/Wetlands Quality Check Point Analysis SVA, NAD27

Point ID	Easting (feet)	Northing (feet)	DEM Elevation (feet)	Dz (feet)
6001	2410342.242	11926188.343	158.840	-0.145
6002	2411679.751	11927213.740	159.820	0.041
6003	2410725.286	11936492.451	165.520	0.243
6004	2415048.667	11941180.839	163.020	-0.024
6005	2416003.293	11944067.632	168.970	-0.195
6006	2418991.308	11944834.933	164.310	0.036
6007	2421593.895	11941328.138	162.010	0.217

6008	2423890.557	11939145.417	178.750	-0.159
6009	2425049.432	11935196.317	175.950	0.965
6010	2426932.130	11929905.375	182.030	-0.135
6011	2420817.852	11921237.610	162.660	0.795
6012	2416151.231	11921328.260	160.900	-0.127
6013	2414024.443	11924480.424	153.060	0.147
6014	2415301.259	11936106.630	156.460	0.347
6015	2413386.631	11936287.094	161.980	0.449
6016	2415820.482	11938215.913	164.190	-0.008
6017	2416632.348	11940771.893	164.870	0.645
6018	2417169.667	11942001.177	165.400	0.137
6019	2420722.450	11939393.805	161.580	-0.246
6020	2424009.082	11937150.609	171.900	-0.039
6021	2421169.269	11943430.642	170.710	0.368
6022	2410545.890	11933132.727	157.590	-0.258

VERTICAL ACCURACY CONCLUSIONS

Swamp/Marsh/Wetlands Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.239 meters supplemental vertical accuracy at the 95th percentile in the Brushlands/Trees supplemental class reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM. Swamp/Marsh/Wetlands Errors larger than 95th percentile include:

- Point 6009, Easting 2425049.432, Northing 11935196.317, Z-Error 0.294 meters
- Point 6011, Easting 2420817.852, Northing 11921237.610, Z-Error 0.242 meters

CONSOLIDATED VERTICAL ACCURACY ASSESSMENT AND CONCLUSION

Consolidated Vertical Accuracy (CVA) Tested 0.141 meters consolidated vertical accuracy at the 95th percentile level; reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM. CVA is based on the 95th percentile error in all land cover categories combined.

- Point 4006, Easting 2420502.206, Northing 11945316.618, Z-Error 0.169 meters
- Point 5014, Easting 2415266.014, Northing 11936001.471, Z-Error 0.144 meters
- Point 6009, Easting 2425049.432, Northing 11935196.317, Z-Error 0.294 meters
- Point 6011, Easting 2420817.852, Northing 11921237.610, Z-Error 0.242 meters
- Point 6017, Easting 2416632.348, Northing 11940771.893, Z-Error 0.197 meters

Accuracy Assessment NAD83 Delivery

The vertical accuracy statistics were calculated by comparison of the lidar bare earth points to the ground surveyed QA/QC points.

Table 5.6: Overall Vertical Accuracy Statistics, NAD83		
Average error	-0.017	meters
Minimum error	-0.080	meters
Maximum error	0.121	meters
Average magnitude	0.037	meters
Root mean square	0.046	meters
Standard deviation	0.044	meters

Table 5.7: Raw Swath Quality Check Point Analysis FVA, NAD83

Point ID	Easting (meters)	Northing (meters)	Laser Elevation (meters)	Dz (meters)
2001	734221.422	3635206.346	49.33	0.011
2002	734922.632	3635840.297	48.27	-0.01
2003	734722.034	3638476.730	51.32	-0.026
2004	736202.165	3639766.957	49.88	-0.017
2005	736385.919	3640818.496	57.51	-0.035
2006	737652.600	3641176.420	60.24	0.009
2007	737757.810	3640069.755	49.29	0.034
2008	738736.898	3639080.015	56.73	-0.069
2009	739098.914	3638048.326	56.29	-0.005
2010	739641.356	3636339.079	56.48	-0.08
2011	737817.028	3633711.354	56.25	0.121
2012	736331.603	3633828.065	48.28	0.004
2013	735446.123	3634647.634	48.79	-0.025
2014	736126.186	3638324.338	48.67	-0.045
2015	735556.473	3638405.257	49.09	0.035
2016	736392.837	3638922.486	50.2	-0.033
2017	736597.487	3639730.570	50.11	-0.032
2018	736633.709	3640087.75	50.97	-0.043
2019	737725.290	3639408.899	49.16	-0.043
2020	738802.779	3638660.825	55.91	-0.008
2021	737874.776	3640603.006	56.32	-0.05
2022	734629.962	3637412.855	48.47	-0.073

VERTICAL ACCURACY CONCLUSIONS

Raw LAS Swath Fundamental Vertical Accuracy (FVA) Tested 0.090 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, using 0.046 meters (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using all points.

LAS Swath Fundamental Vertical Accuracy (FVA) Tested 0.107 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using 0.055 meters (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using just ground points.

Bare-Earth DEM Fundamental Vertical Accuracy (FVA) Tested 0.111 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using 0.057 meters (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM.

SUPPLEMENTAL VERTICAL ACCURACY ASSESSMENTS

Table 5.8: Tall Weeds and Crops Quality Check Point Analysis SVA, NAD83

Point ID	Easting (meters)	Northing (meters)	DEM Elevation (meters)	Dz (meters)
4001	734247.260	3635189.995	49.270	-0.092
4002	734921.154	3635826.291	47.930	-0.051
4003	734769.630	3638472.479	51.620	-0.079
4004	736200.493	3639723.284	49.720	0.049
4005	736786.682	3641330.931	57.120	-0.028
4006	737692.140	3641133.449	60.580	-0.174
4007	737804.893	3640043.065	49.150	0.085
4008	738774.398	3639124.664	55.550	-0.013
4009	739105.772	3637943.716	54.030	-0.051
4010	739665.804	3636350.882	54.500	-0.027
4011	737910.765	3633693.323	50.190	-0.071
4012	736551.101	3633872.788	54.140	0.029
4013	735480.598	3634663.498	48.050	0.078
4014	736036.505	3638309.432	55.370	-0.024
4015	735526.713	3638433.085	49.850	0.131
4016	736400.325	3638943.465	50.370	0.005
4017	736572.301	3639726.147	49.980	-0.132
4018	736627.532	3640045.580	51.180	-0.012
4019	737757.492	3639420.208	49.510	0.082
4020	738691.107	3638753.835	52.150	0.005
4021	737848.092	3640619.721	55.310	0.267
4022	734545.249	3637568.716	48.820	-0.076

VERTICAL ACCURACY CONCLUSIONS

Tall Weeds and Crops Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.171 meters supplemental vertical accuracy at the 95th percentile in the Tall Weeds and Crops supplemental class reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM. Tall Weeds and Crops Errors larger than 95th percentile include:

- Point 4006, Easting 737692.140, Northing 3641133.449, Z-Error 0.174 meters
- Point 4021, Easting 737848.092, Northing 3640619.721, Z-Error 0.267 meters

Table 5.9: Brushlands and Trees Quality Check Point Analysis SVA, NAD83

Point ID	Easting (meters)	Northing (meters)	Laser Elevation (meters)	Dz (meters)
5001	734239.200	3635180.107	49.060	-0.004
5002	734909.863	3635874.531	47.790	0.039
5003	734864.146	3638536.937	50.150	0.113
5004	736217.315	3639807.959	49.070	-0.05
5005	736741.329	3641317.645	57.060	-0.07
5006	737358.605	3641014.438	52.230	-0.043
5007	737586.747	3640018.540	49.690	-0.051
5008	738783.786	3639183.149	55.560	-0.049
5009	739089.989	3637962.326	53.580	-0.071
5010	739686.928	3636422.016	54.780	0.129
5011	737882.038	3633738.071	50.190	-0.008
5012	736279.304	3633761.471	48.400	0.091
5013	735508.232	3634701.470	48.500	0.011
5014	736096.119	3638294.174	48.020	0.146
5015	735547.460	3638358.360	49.580	0.062
5016	736374.140	3638959.775	49.700	-0.006
5017	736582.752	3639778.694	49.630	-0.008
5018	736616.643	3640078.486	51.010	0.069
5019	737765.169	3639362.983	49.170	0.128
5020	738824.455	3638690.382	56.180	-0.007
5021	737833.953	3640622.462	51.960	-0.096
5022	734629.196	3637515.781	48.300	-0.045

VERTICAL ACCURACY CONCLUSIONS

Brushlands/Trees Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.128 meters supplemental vertical accuracy at the 95th percentile in the Tall Weeds/Crops supplemental class reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM. Brushlands/Trees Errors at the 95th percentile include:

- Point 5010, Easting 739686.928, Northing 3636422.016, Z-Error 0.129 meters
- Point 5014, Easting 736096.119, Northing 3638294.174, Z-Error 0.146 meters

Table 5.10: Swamp/Marsh/Wetlands Quality Check Point Analysis SVA, NAD83

Point ID	Easting (meters)	Northing (meters)	Laser Elevation (meters)	Dz (meters)
6001	734595.321	3635303.113	48.430	-0.029
6002	735003.000	3635615.654	48.680	-0.021
6003	734712.093	3638443.834	50.380	0.004
6004	736029.880	3639872.861	49.700	0.004
6005	736320.857	3640752.762	51.510	-0.051
6006	737231.614	3640986.633	50.100	0.029
6007	738024.884	3639917.747	49.250	-0.065
6008	738724.909	3639252.443	54.470	-0.061

6009	739078.131	3638048.744	53.590	0.255
6010	739651.974	3636436.045	55.470	-0.054
6011	737788.310	3633794.095	49.540	0.204
6012	736365.910	3633821.735	49.030	-0.051
6013	735717.664	3634782.527	46.700	0.092
6014	736106.862	3638326.227	47.690	0.107
6015	735523.278	3638381.236	49.350	0.115
6016	736265.126	3638969.141	49.980	-0.068
6017	736512.589	3639748.210	50.120	0.064
6018	736676.368	3640122.899	50.410	0.038
6019	737759.262	3639328.158	49.230	-0.095
6020	738761.033	3638644.420	52.380	-0.027
6021	737895.460	3640558.597	52.020	0.100
6022	734657.406	3637419.781	48.060	-0.052

VERTICAL ACCURACY CONCLUSIONS

Swamp/Marsh/Wetlands Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.199 meters supplemental vertical accuracy at the 95th percentile in the Brushlands/Trees supplemental class reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM. Swamp/Marsh/Wetlands Errors larger than 95th percentile include:

- Point 6009, Easting 739078.131, Northing 3638048.744, Z-Error 0.255 meters
- Point 6011, Easting 737788.310, Northing 3633794.095, Z-Error 0.204 meters

CONSOLIDATED VERTICAL ACCURACY ASSESSMENT AND CONCLUSION

Consolidated Vertical Accuracy (CVA) Tested 0.141 meters consolidated vertical accuracy at the 95th percentile level; reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM. CVA is based on the 95th percentile error in all land cover categories combined.

- Point 4006, Easting 737692.140, Northing 3641133.449, Z-Error 0.174 meters
- Point 4021, Easting 737848.092, Northing 3640619.721, Z-Error 0.267 meters
- Point 5014, Easting 736096.119, Northing 3638294.174, Z-Error 0.146 meters
- Point 6009, Easting 739078.131, Northing 3638048.744, Z-Error 0.255 meters
- Point 6011, Easting 737788.310, Northing 3633794.095, Z-Error 0.204 meters

Approved by:	Name	Signature	Date
Associate Member, Lidar Specialist Certified Photogrammetrist #1381	Qian Xiao		July 2015

Section 6: Flight Logs

Flight logs for the project are shown on the following pages:

KEYSTONE AERIAL SURVEYS

Keystone Aerial Surveys, Inc. - LIDAR FLIGHT REPORT - v1.2

Date: 4 / 18 / 15 Pilot: RB

Project: KAS15CA1022 Operator: JH

Aircraft: N61254

Sensor: 08 SEN 236 HD: GOOD STATE

POS/AV Filename: 20150418

Flight Plan		Weather	
Roll Comp:	On or Off	Pressure (gnd):	2995
Multipulse:	On or Off	Temperature (gnd):	90°
Beam Divergence:	Wide or Narrow	Temperature (air):	75°
Scan Rate:	61	Dew Point:	
Pulse Rate:	70	Turbulence:	YES
Scan Angle:	12.3	Visibility:	10 miles
Desired Range:	600		
Planned GPS:			

Line #	Start Time	End Time	HDG	Range	PDOP	SV	Speed (kts)	Flight Notes
2	9:10	9:12	224	600	1.46	20	101	KNYL AIRPORT CAL!
2	9:15	9:17	44	600	1.47	20	110	
1	9:22	9:23	133	600	1.47	20	110	
33	9:33	9:34	9	605	1.47	19	105	KAS 15CA-1022
31	9:38	9:39	9	600	1.84	17	92	
32	9:44	9:45	189	610	1.83	17	105	
30	9:48	9:49	9	609	1.80	17	105	
29	9:53	9:56	189	603	1.47	18	100	
28	9:59	10:01	9	605	1.46	18	105	
27	10:05	10:08	189	604	1.45	18	106	
26	10:12	10:14	9	605	2.01	17	105	
25	10:17	10:20	189	598	1.97	16	104	
24	10:23	10:26	9	607	1.91	17	102	
23	10:29	10:33	189	605	1.84	17	100	
22	10:36	10:39	9	615	1.77	17	105	
21	10:43	10:46	189	620	1.98	17	100	
20	10:50	10:53	9	605	1.62	18	107	
19	10:56	10:59	189	610	1.59	17	101	
18	11:02	11:04	9	603	1.55	17	100	
17	11:08	11:11	189	610	150	17	105	

Base Station

Point ID: KNYL

Position Type: Known / Autonomous

Antenna Height: 2 Meters

Latitude: 32 39 46.16

Longitude: -114 36 30.68

Location: YUMA AZ

Time On: 15:19 UTC

Time Off: 21:22 UTC

PDOP: 1.61

SV's 19

Airborne Station

Time On: 16:49 UTC

Kinematic On: 16:55 UTC

Kinematic Off: 21:05 UTC

Time Off: 21:11 UTC

Engine Start:	9:30
Engine Off:	13:12
Flight Time:	

Page 1 of 2

Keystone Aerial Surveys, Inc. - LIDAR FLIGHT REPORT - v1.2

KEYSTONE AERIAL SURVEYS

Date: 04/18/15 Pilot: RB
Project: KAS15CA1022 Operator: JA
Aircraft: N91851
Sensor: 08SEN236 HD: SOLID STATE

POS/AV Filename: 20150418

Flight Plan	
Roll Comp:	On or Off (On circled)
Multipulse:	On or Off (Off circled)
Beam Divergence:	Wide or Narrow (Narrow circled)
Scan Rate:	61
Pulse Rate:	70
Scan Angle:	12.3
Desired Range:	600
Planned GPS:	

Weather	
Pressure (gnd):	2995
Temperature (gnd):	80°
Temperature (air):	75°
Dew Point:	
Turbulence:	YES
Visibility:	+10 MILES

Line #	Start Time	End Time	HDG	Range	PDOP	SV	Speed (kts)	Flight Notes
16	11:14	11:17	9	620	1.67	18	97	
15	11:20	11:23	189	602	1.66	17	105	
14	11:26	11:29	9	605	1.33	19	107	
13	11:32	11:35	189	610	1.33	18	106	
12	11:38	11:42	9	620	1.31	17	105	
11	11:44	11:47	189	610	1.59	17	103	
10	11:50	11:54	9	605	1.60	17	105	
9	11:56	12:00	189	607	1.61	17	102	
8	12:02	12:05	9	620	1.69	17	103	
7	12:08	12:10	189	615	1.66	18	98	
6	12:13	12:15	9	610	1.72	18	110	
5	12:18	12:21	189	605	1.78	18	101	
4	12:24	12:26	9	605	1.81	19	105	
3	12:29	12:31	189	620	1.88	19	100	
2	12:35	12:36	9	610	2.01	18	107	
1	12:39	12:41	189	625	2.07	19	99	
TIE	12:45	12:47	99	600	2.09	19	99	TIE LINE
TIE	12:49	12:51	279	610	2.11	18	100	WEST PART ONLY

Base Station

Point ID: KNYL
Position Type: Known / Autonomous (Autonomous circled)
Antenna Height: 2 Meters
Latitude: 32 39 46.16
Longitude: -114 36 30.68
Location: YUMA AZ
Time On: 15:19 UTC
Time Off: 21:22 UTC
PDOP: 1.61
SV's 19

Airborne Station

Time On: 16:44 UTC
Kinematic On: 16:55 UTC
Kinematic Off: 21:05 UTC
Time Off: 21:11 UTC

Engine Start:	8:30
Engine Off:	13:12
Flight Time:	

Page 2 of 2

Section 7: Final Deliverables

The final lidar deliverables are listed below.

- LAS v1.2 classified point cloud
- LAS v1.2 raw unclassified point cloud flight line strips no greater than 2GB.
- Tile layout and data extent provided as ESRI shapefile
- Hydro Breaklines as ESRI shapefile
- Digital Elevation Model in ERDAS .IMG format
- 8-bit intensity images in .TIF format
- Flightline Vectors provided as ESRI shapefile
- Control Points provided as ESRI shapefile
- FGDC compliant metadata per product in XML format
- Lidar processing report in pdf format