AIRBORNE LIDAR REPORT

ELWHA RIVER, WA LIDAR

UNITED STATES GEOLOGICAL SURVEY (USGS)

CONTRACT NUMBER: G10PC00057

TASK ORDER NUMBER: G11PD01088

Woolpert Project Number: 71910

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ELWHA RIVER, WA, LIDAR

This report contains a comprehensive outline of the task order consisting of approximately thirty-five (35) square mile area along the Elwha River in Washington for the United States Geological Survey (USGS). This data will be used to assist the Department of Interior with the Elwha River Restoration Project following the removal of the Elwha Dam. The LiDAR data was acquired and processed to meet the task order requirement of a 1.0 meter Nominal Pulse Spacing (NPS). The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.

Woolpert teammate, Watershed Sciences Inc. (WSI), acquired the LiDAR data using a Leica ALS60 sensor. The LiDAR data was acquired using the following sensor settings:

Table 1. Sensor Settings

Survey Altitude (AGL)	900m
Target Pulse Rate	106 kHz
Sensor Configuration	Single Pulse in Air (SPiA)
Laser Pulse Diameter	21 cm
Mirror Scan Rate	66.3 H_z
Field of View	26^0
GPS Baselines	≤13 nm
GPS PDOP	≤3.2
GPS Satellite Constellation	≥6
Maximum Returns	4
Intensity	8-bit
Resolution/Density	Average 8 pulses per square meter
Accuracy	RMSEZ ≤ 15 cm

The Area of Interest (AOI) was surveyed with an opposing flight line side-lap of =50% (=100% overlap) to reduce laser shadowing and increase surface laser painting. The Leica laser systems record up to four range measurements (returns) per pulse. All discernible laser returns were processed for the output dataset.

LiDAR data was processed and projected in UTM, Zone 10N, North American Datum of 1983 (NAD83) in units of meters. The vertical datum used for the task order was referenced to NAVD 1988, meters, GEOID09.

A portion of the task order AOI was tidal influenced. The LiDAR data acquisition was planned based on the tidal water level was to be no greater than 0.4 meters above Mean Lower Low Water (MLLW) at the NOAA tidal gauge at Port Angeles, WA (Station 9444090). The following web site was used to monitor tide predictions for the Port Angeles, WA tidal gauge:

http://tidesandcurrents.noaa.gov/noaatidepredictions/viewDailyPredictions.jsp?Stationid=9444090

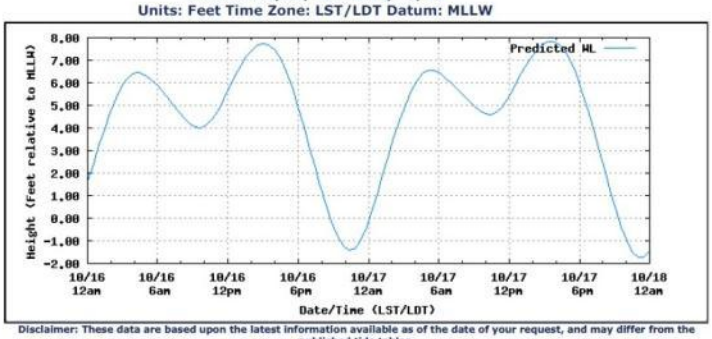
The LiDAR data acquisition window for the task order opened on October 1, 2012. The LiDAR data acquisition was started on October 10, 2012 in the upper river area. The aircraft remained on-station in Port Angeles, WA, but poor weather prohibited additional acquisition until October 15, 2012. On October 16, 2012 the tidal influenced portion of the AOI was acquired between 2120 (October 16, 2012) to 0020 (October 17, 2012) during the required low tide conditions.

Figure 1. Tidal influenced portion of the Elwha River, WA, task order AOI

Figure 2. Daily Tide Prediction for Port Angeles, WA on October 16-17, 2012

Help Print

NOAA/NOS/CO-OPS
Daily Tide Prediction for PORT ANGELES,WA
StationId 9444090
From: 2012/10/16 - 2012/10/17
Units: Feet Time Zone: LST/LDT Datum: MLLW



Disclaimer: These data are based upon the latest information available as of the date of your request, and may differ from the published tide tables.

High/Low Tide Predictions

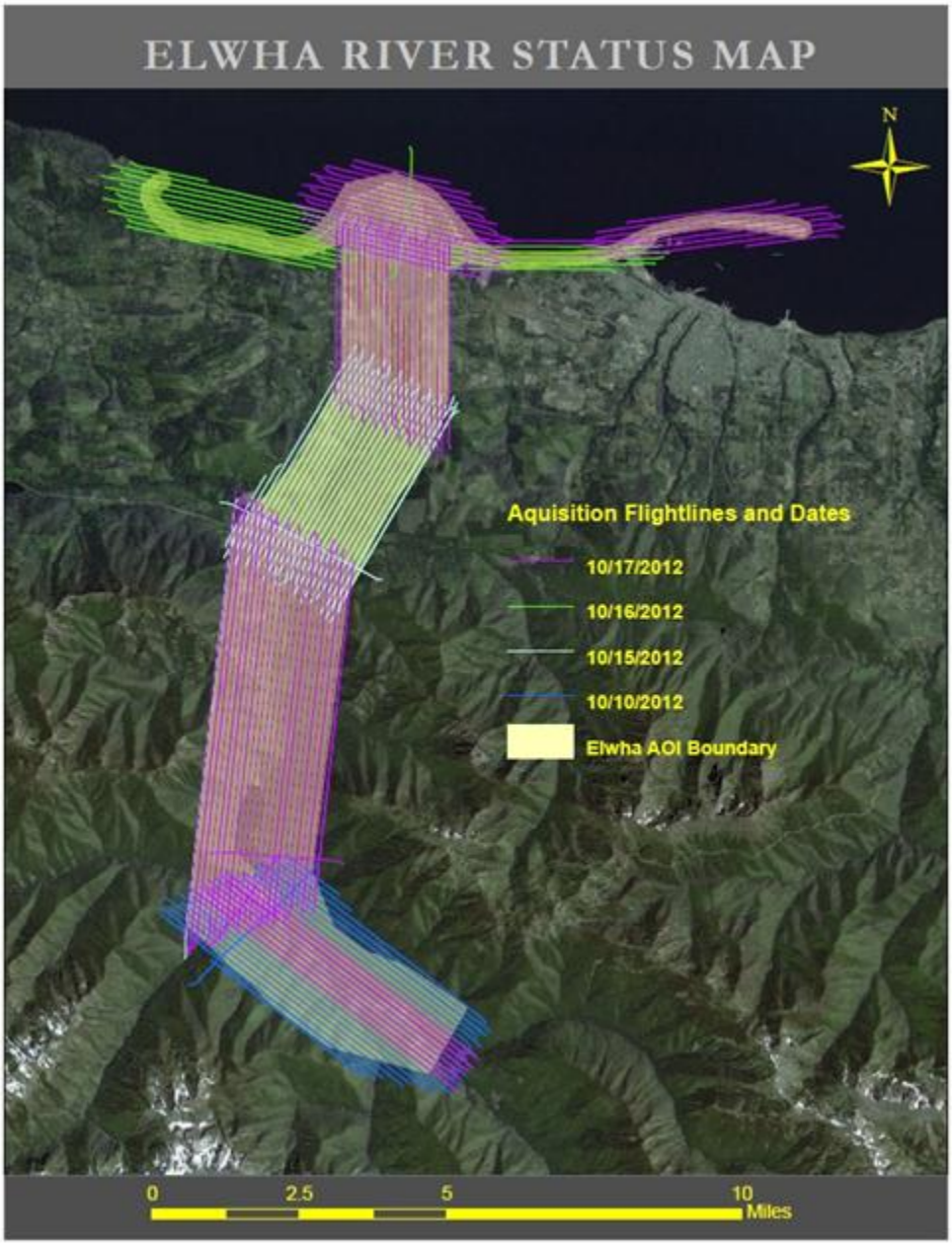
Station Name: PORT ANGELES,WA
Parameter: Daily
Product: Tide Prediction
Start Date & Time: 2012/10/16 12:00AM
End Date & Time: 2012/10/17 11:59PM

Source: NOAA/NOS/CO-OPS
Prediction Type: Harmonic
Datum: MLLW
Height Units: Feet
Time Zone: LST/LDT

Date	Day	Time	Hgt	Time	Hgt	Time	Hgt	Time	Hgt
2012/10/16	Tue	04:21 AM	6.46 H	09:35 AM	4.0 L	03:04 PM	7.74 H	10:26 PM	-1.42 L
2012/10/17	Wed	05:20 AM	6.57 H	10:20 AM	4.58 L	03:35 PM	7.83 H	11:14 PM	-1.76 L

The remaining areas were acquired on October 17, 2012. The valley bottom on the upper areas was re-acquired in order to capture the river gradient under the same flow conditions.

Figure 3. Elwha River, WA Task Order AOI Dates of LiDAR Data Acquisition



To accurately solve for laser point position (geographic coordinates x, y, z), the positional coordinates of the airborne sensor and the attitude of the aircraft were recorded continuously throughout the LiDAR data acquisition. Position of the aircraft was measured twice per second (2 Hz) by an onboard differential GPS unit. The aircraft attitude was measured 200 times per second (200 Hz) pitch, roll, and yaw (heading) by an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft/sensor position and attitude data are indexed by GPS time.

Ground survey data was used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data products. Surveyors set permanent monuments and collect real time kinematic (RTK) surveys to support the airborne LiDAR acquisition process.

The spatial configuration of the ground survey monuments provided redundant control within 13 nautical miles of the mission area for LiDAR flights. Monuments were also used for collection of ground control points using RTK survey techniques.

Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for RTK coverage. WSI survey staff used one existing monument (JFCM_02) and established 3 new monuments for the Elwha River LiDAR project. New monumentation was set using 5/8" rebar topped with stamped 2" aluminum caps. WSI Professional Land Surveyor Chris Yotter-Brown (WAPLS#46328) supervised and certified the monumentation for the Elwha River site.

Monuments established for the Elwha River LiDAR acquisition. Coordinates are on the NAD83 (CORS96) datum, epoch 2002.

Table 2. Coordinates

Monument ID	Latitude	Longitude	Ellipsoid (meters)
JFCM_02	48 08 39.90629	-123 33 18.29779	-13.683
ELWAH_01	48 05 10.60480	-123 33 35.69792	154.300
ELWHA_02	48 03 45.56787	-123 32 30.00422	171.934
ELWHA_03	48 06 16.06604	-123 32 11.49350	98.171

To correct the continuous onboard measurements of the aircraft position recorded throughout the missions, WSI concurrently conducted multiple static Global Navigation Satellite System (GNSS) ground surveys (1 Hz recording frequency) over each monument. After the airborne survey, the static GPS data were triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS1) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

All static surveys were collected with Trimble model R7 GNSS receivers equipped with a Zephyr Geodetic Model 2 RoHS antenna. All GNSS measurements were made with dual frequency L1-L2 receivers with carrier-phase correction.

Upon completion of the LiDAR data acquisition, the processing staff initiated a suite of automated and manual techniques to process the data into the requested deliverables. Processing tasks included GPS control computations, kinematic corrections, calculation of laser point position, calibration for optimal relative and absolute accuracy, and classification of ground and non-ground points. Processing methodologies were tailored for the landscape and intended application of the point data.

The LiDAR LAS files for this task order have been classified into the Default (Class 1), Ground (Class 2), Noise (Class 7), Water (Class 9), and Ignored Ground (Class 10).

Table 3. Processing Steps and Software

LiDAR Processing Steps	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data.	Waypoint GPS v.8.3 Trimble Business Center v.2.80 Blue Marble Desktop v.2.5
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor head position and attitude are	IPAS TC v.3.1

Table 3. Processing Steps and Software

LiDAR Processing Steps	Software Used
calculated throughout the survey. The SBET data are used extensively for laser point processing.	
Calculate laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Create raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.2) format. Data are converted to orthometric elevations (NAVD88) by applying a Geoid03 correction.	ALS Post Processing Software v.2.74
Import raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filter erroneous points. Ground points are then classified for individual flight lines (to be used for relative accuracy testing and calibration).	TerraScan v.12.004
Using ground classified points per each flight line, the relative accuracy is tested. Automated line-to-line calibrations are then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calibrations are performed on ground classified points from paired flight lines. Every flight line is used for relative accuracy calibration.	TerraMatch v.12.001
Import position and attitude data. Classify resulting data as ground and non-ground points. Assess statistical absolute accuracy via direct comparisons of ground classified points to ground RTK survey data.	TerraScan v.12.004 TerraModeler v.12.002
Generate bare earth models as triangulated surfaces. Highest hit models were created as a surface expression of all classified points (excluding the withheld class). All surface models were exported as GeoTIFFs at a 1 meter pixel resolution.	TerraScan v.12.004 ArcMap v. 10.0 TerraModeler v.12.002

For the RTK check point data collection, a Trimble R7 base unit was positioned at a nearby monument to broadcast a kinematic correction to a roving Trimble R8 GNSS receiver. All RTK measurements were made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 with at least six satellites in view of the stationary and roving receivers. When collecting RTK data, the rover would record data while stationary for five seconds, then calculate the pseudorange position using at least three one-second epochs. Relative errors for the position must be less than 1.5 cm horizontal and 2.0 cm vertical in order to be accepted. The RTK positions were collected on hard surface locations such as gravel or stable dirt roads that also had good satellite visibility. RTK measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads due to the increased noise seen over these types of features. The distribution of RTK points depended on ground access constraints and may not be equitably distributed throughout the study area. In addition to the control points, land cover category checkpoints were surveyed throughout the task order AOI.

The LAS data covering the Elwha River, WA LiDAR Task Order was compared to survey control points to determine the FVA of the LAS Swath and of the Bare-Earth DEM. In addition, this LAS data was compared to checkpoints from the following categories: Bare Earth/Open Terrain, Tall Weeds/Crops, and Forested and Fully Grown. The LAS Swath Fundamental Vertical Accuracy (FVA) Tested 0.152m (15.2cm) fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using 0.078m (7.8cm) (RMSE(z) x 1.96000 tested against the TIN. Bare-Earth DEM Fundamental Vertical Accuracy (FVA) Tested 0.162m (16.2cm) fundamental

vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using 0.083m (8.3cm) (RMSE(z) x 1.96000 tested against the DEM.

The land cover types and descriptions can be referenced in the following table.

Table 4. Land Cover Types

Land Cover Category	Land Cover Code	Example	Description
Bare Earth/Open Terrain	**OPEN**		Areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clear cuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.).
Tall Weeds/Crops	**TALL_WEEDS**	 	Vegetation is less than 6 meters tall; Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms.
Forested and Fully Grown	**FOREST**		Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.

The Bare-Earth DEM Fundamental Vertical Accuracy (FVA) tested 0.162 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using RMSE(z) x 1.96000. This data set was tested against the DEM using independent check points.

Table 5. Bare Earth/Open Terrain QA/QC Analysis, UTM, Zone 10N, NAD83, NAVD 1988, GEOID09, meters

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Absolute Dz (meters)
100	455552.145	5322317.051	145.360	0.040
101	459328.909	5331650.715	9.540	0.110
102	460182.294	5331561.095	47.323	0.047
103	460176.415	5331601.574	45.955	0.115
104	455562.388	5322330.764	144.869	0.141
106	455555.814	5322326.745	145.136	0.144
111	459327.949	5331773.836	7.713	0.133
112	459094.037	5331538.178	11.131	0.079
113	459095.056	5331559.346	10.676	0.044
115	459095.766	5331586.623	10.535	0.125
116	459096.817	5331529.004	11.142	0.148
172	458148.854	5329308.258	87.207	0.007
173	459854.726	5330428.190	64.842	0.042
174	457410.807	5326684.787	190.236	0.066
176	457410.357	5326676.064	189.632	0.018
177	459827.832	5330408.153	65.782	0.032
178	457414.252	5326653.513	188.359	0.009
179	459606.288	5328797.943	99.246	0.014
180	457414.365	5326665.516	188.985	0.005
181	459856.468	5330438.084	64.285	0.125
182	457368.340	5326688.258	190.194	0.026
183	459596.184	5328857.909	100.262	0.002
184	458194.797	5329327.705	85.727	0.053
185	458094.146	5329330.053	81.775	0.005
186	457393.180	5326651.976	188.502	0.018
187	459628.308	5328820.585	99.782	0.038
189	457380.830	5326666.046	189.376	0.034
190	459623.067	5328801.689	99.555	0.045
191	459863.202	5330448.541	63.319	0.081
192	459944.850	5330409.610	62.959	0.041
193	457406.158	5326692.308	190.444	0.066
194	459864.032	5330389.843	65.111	0.059
195	458135.642	5329313.010	87.211	0.129
196	459929.162	5330404.599	63.844	0.096
197	459905.979	5330397.389	64.202	0.108
198	459849.379	5330419.092	64.519	0.061
199	459836.759	5330416.797	65.591	0.119
200	459883.955	5330395.543	64.714	0.076
201	457409.902	5326697.420	190.883	0.027
202	459625.240	5328835.911	100.062	0.012
203	460054.718	5329334.602	89.895	0.085
204	459846.493	5330398.705	65.211	0.089
205	459617.314	5328842.122	100.059	0.141
206	457355.372	5326700.672	190.503	0.107
208	460046.995	5329330.992	89.452	0.078
211	460060.870	5329342.929	89.714	0.126
212	460045.749	5329349.034	88.713	0.107

The Bare Earth/Open Terrain Land Cover Classification Supplemental Vertical Accuracy (SVA) tested 0.143 meters supplemental vertical accuracy at the 95th percentile in Bare Earth/Open Terrain. Tested against the DEM. Errors larger than 95th percentile include:

- Point 106, Easting 455555.814, Northing 5322326.745, Absolute Z-Error 0.144
- Point 116, Easting 459096.817, Northing 5331529.004, Absolute Z-Error 0.148

Table 6. Tall Weeds/Crops QA/QC Analysis, UTM, Zone 10N, NAD83, NAVD 1988, GEOID09, meters

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Absolute Dz (meters)
117	460181.877	5331557.734	47.520	0.120
118	460068.093	5328079.720	116.629	0.111
119	458522.674	5329679.462	38.019	0.091
120	460072.980	5328057.332	117.345	0.075
121	460078.214	5328064.652	117.111	0.099
122	458856.242	5333096.511	2.808	0.112
123	460202.327	5331579.212	46.581	0.079
124	460073.523	5328072.243	116.860	0.100
125	460065.571	5328050.359	117.602	0.128
126	458520.561	5329666.931	38.187	0.163
127	458508.367	5329700.279	37.761	0.149
128	458515.835	5329693.707	37.770	0.140
129	458513.810	5329684.897	37.782	0.258
132	459329.617	5331763.888	7.407	0.013
133	460236.132	5331992.544	35.260	0.001
134	460233.110	5331976.257	35.497	0.043
135	460236.697	5332013.179	35.096	0.034
136	460127.319	5331650.052	43.291	0.069
137	458494.864	5329660.072	38.227	0.083
138	455996.630	5320507.270	88.376	0.054
139	455998.094	5320850.318	81.209	0.081
140	456010.852	5320837.719	81.329	0.071
141	458608.821	5329473.222	41.050	0.010
142	460138.639	5331637.667	44.083	0.117
143	458845.999	5333031.099	3.092	0.138
144	460144.078	5331615.043	45.129	0.031
145	456019.514	5320824.313	81.457	0.103
146	456007.710	5320814.789	81.276	0.114
147	455957.774	5320602.742	82.304	0.126
148	455982.057	5320531.776	85.623	0.177
149	459316.867	5327670.276	122.579	0.091
150	455985.242	5320521.291	86.300	0.150
151	455985.128	5320500.360	87.638	0.202
152	456019.848	5320803.115	81.376	0.144
153	455979.498	5320511.794	86.596	0.164
154	458877.033	5333107.874	2.474	0.156
155	455949.290	5320601.323	82.405	0.175
156	458869.961	5333092.145	2.912	0.218
157	455974.036	5320501.785	86.416	0.204
158	455941.880	5320597.031	82.367	0.263
159	459299.918	5327658.190	122.764	0.146
160	458541.155	5329577.725	39.590	0.240

Table 6. Tall Weeds/Crops QA/QC Analysis, UTM, Zone 10N, NAD83, NAVD 1988, GEOID09, meters

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Absolute Dz (meters)
161	458725.368	5332562.247	4.577	0.193
162	458731.469	5332570.908	4.614	0.216
163	458740.999	5332555.857	4.565	0.215
164	458547.447	5329537.092	39.639	0.201
165	459327.608	5331785.277	7.523	0.207
166	458504.604	5329640.392	38.211	0.239
167	458742.638	5332568.325	4.534	0.266
168	458751.388	5332562.195	4.249	0.291
169	458866.554	5333118.706	2.427	0.293
170	459282.631	5327659.036	121.790	0.340

The Tall Weeds/Crops Land Cover Classification Supplemental Vertical Accuracy (SVA) tested 0.291 meters supplemental vertical accuracy at the 95th percentile in Tall Weeds/Crops. Tested against the DEM. Tall Weeds/Crops larger than 95th percentile include:

- Point 169, Easting 458866.554, Northing 5333118.706, Absolute Z-Error 0.293

Table 7. Forested and Fully Grown QA/QC Analysis, UTM, Zone 10N, NAD83, NAVD 1988, GEOID09, meters

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Absolute Dz (meters)
210	458183.328	5329320.717	46.250	85.833
215	459676.297	5328485.267	103.665	0.075
216	456473.349	5323452.273	101.445	0.005
217	459866.026	5328481.303	104.820	0.010
218	456480.886	5323443.682	100.869	0.031
219	456506.952	5323402.782	100.353	0.097
220	456495.681	5323422.266	100.009	0.061
221	459845.681	5328482.218	104.721	0.049
222	457170.892	5326306.779	176.034	0.046
223	456110.953	5319906.520	99.484	0.054
224	457335.391	5323542.729	71.474	0.116
225	457170.443	5326295.326	175.928	0.102
226	456445.956	5323471.995	102.514	0.126
227	458161.696	5329316.433	87.074	0.116
228	457175.048	5326287.268	174.010	0.130
229	456499.584	5323413.874	100.057	0.113
230	455892.692	5320555.697	82.653	0.157
231	457181.608	5326297.830	174.280	0.190
232	456000.501	5320561.692	84.602	0.198
233	459936.682	5328485.045	104.391	0.239

The Forested and Fully Grown Land Cover Classification Supplemental Vertical Accuracy (SVA) tested 0.236 meters supplemental vertical accuracy at the 95th percentile in Forested and Fully Grown. Tested against the DEM. Forested and Fully Grown Errors larger than 95th percentile include:

- Point 233, Easting 459936.682, Northing 5328485.045, Absolute Z-Error 0.239

The Consolidated Vertical Accuracy (CVA) tested 0.258meters consolidated vertical accuracy at the 95th percentile level, derived according to ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data. This data set was tested against the DEM using independent check points. Based on the 95th percentile error in all land cover categories combined. Combined Land Cover Errors larger than 95% include:

- Point 158, Easting 455941.880, Northing 5320597.031, Absolute Z-Error 0.263
- Point 167, Easting 458742.638, Northing 5332568.325, Absolute Z-Error 0.266
- Point 168, Easting 458751.388, Northing 5332562.195, Absolute Z-Error 0.291
- Point 169, Easting 458866.554, Northing 5333118.706, Absolute Z-Error 0.293
- Point 170, Easting 459282.631, Northing 5327659.036, Absolute Z-Error 0.340

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