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**140G0218F0164 Southern, NJ Lidar (4-County)**  
**USGS Contract: G16PC00051**

# Lidar Report

June, 2020

## EXECUTIVE SUMMARY

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[The U.S. Geological Survey](#) (USGS) contracted with [The Sanborn Map Company, Inc.](#) (Sanborn) to provide remote sensing services for South NJ in the form of Lidar. Utilizing a multi-return system, Light Detection and Ranging (Lidar) detects 3-dimensional positions and attributes to form a point cloud. The high accuracy airborne system is integrated with both Global Navigation Satellite System (GNSS) and an Inertial Measure Unit (IMU) for accurate position and orientation. Acquisition of the project area's ~1,794mi<sup>2</sup> was completed on April 23<sup>rd</sup>, 2019.

The Riegl VQ-1560i was used to collect data for the aerial survey campaign. The sensor is attached to the aircraft's underside and emits rapid laser pulses that are used to calculate ranges between the aircraft and subsequent terrain below. The Airborne Lidar System (ALS) is boresighted by completing multiple passes over a known ground surface before the project acquisition. During data processing, the calibration parameters are updated and used during post-processing of the lidar point cloud.

Differential GNSS unit in aircraft sampled positions at 2Hz or higher frequency. Lidar data was only acquired when GNSS PDOP is  $\leq 4$  and at least 6 satellites are in view. Collection conditions were for leaf-off vegetation. The atmosphere was free of clouds and fog between the aircraft and ground. The ground was free of snow and extensive flooding or any other type of inundation

The contents of this report summarize the methods used to establish the base station coordinates, perform the lidar data acquisition and processing as well as the results of these methods.

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## 1.0 INTRODUCTION

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This document contains the technical write-up of the lidar campaign, including system calibration techniques, and the collection and processing of the lidar data.

### 1.1 Contact Information

Questions regarding the technical aspects of this report should be addressed to:

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### 1.2 Purpose of Lidar Acquisition

The objective of this project is to collect accurate measurements of the bare-earth surface as well as above ground features to be provided as geometric inputs for surface and/or change modeling as is relates survey assessments.

### 1.3 Project Location

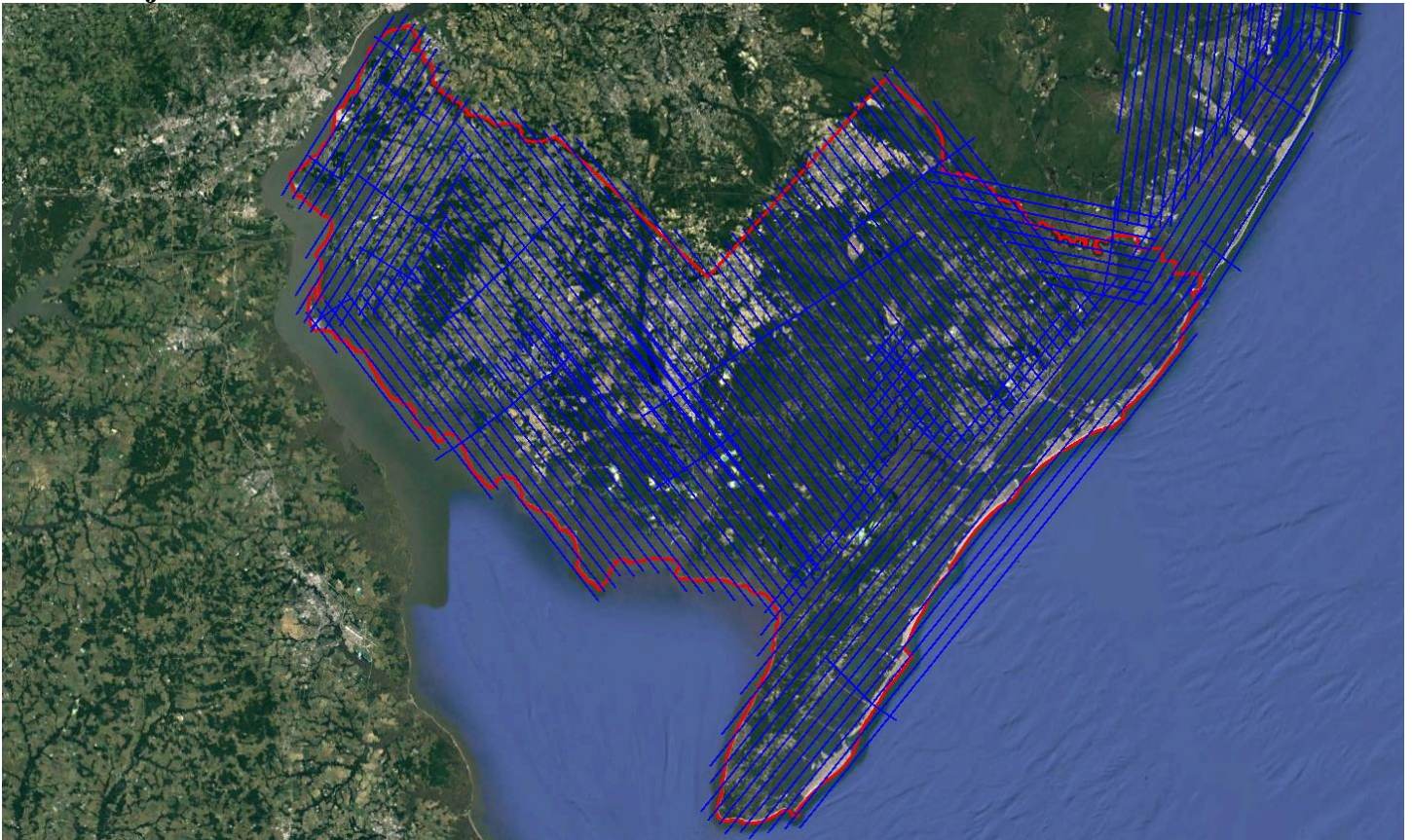


Figure 1: AOI and Trajectories As-Flown

## 2.0 ACQUISITION

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### 2.1 Introduction

This section outlines the lidar system, flight reporting and data acquisition methodology used during the collection of the Southern, NI lidar campaign. Although Sanborn conducts all lidar missions with the same rigorous and strict procedures and processes, all lidar collections are unique.

### 2.2 Acquisition Parameters

Sanborn specifically defined the collection parameters to accomplish the desired project specifications. **Table 1** shows the planned acquisition parameters utilized for this aerial survey with the sensor(s) installed.

Planned Acquisition Parameters	
Sensor	Riegl VQ-1560i
Aircraft	C-FVZM Piper Navajo PA-31
Flying Height (AGL)	1700
Air Speed (kts)	160
Field of View (degrees)	60
Overlap (%)	30
Pulse Rate (kHz)	1000
Scan Rate (Hz)	232
Laser Footprint (m)	0.43
Mode (PIA)	Yes
Point Spacing (m)	0.5
Point Density (pls/m <sup>2</sup> )	4.1
Swath Width (m)	1905

Table 1: Lidar Acquisition Parameters

### 2.3 Field Work Procedures

Sanborn's standard procedure before every mission is to perform pre-flight checks to ensure correct operation of all systems. All cables were checked and the sensor head glass was cleaned. A three-minute static session was conducted on the ground with the engines running prior to take-off in order to establish fine-alignment of the IMU and to resolve GNSS ambiguities.

The project acquisition consisted of thirteen (13) missions. During the data collection, the operator recorded information on log sheets which includes weather conditions, lidar operation parameters, flight line statistics and PDOP. Near the end of each mission, GNSS ambiguities are again resolved by flying within ten kilometers of the base stations to aid in post-processing.

Preliminary data processing was performed in the field immediately following the missions for quality control of GNSS data and to ensure sufficient coverage of the project AOI. Any problematic data could then be re-flown immediately as required. Final data processing was completed in the Colorado Springs, CO office. **Table 2** below shows the flight acquisition metrics for the entire collection. **Table 3** contains the base station names and locations in operation during acquisition. Base station coordinates are provided in NAD83 (2011), Geographic Coordinate System, Ellipsoid, Meters.

Date	Sensor	Serial #	Tail #	MissionID	PDOP	Start (UTC)	End (UTC)
3/8/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190308_1	1.8	16:12:22	20:04:44
3/11/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190311_1	2.1	14:54:25	20:16:43
3/13/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190313_1	1.8	13:58:15	19:53:52
3/14/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190314_1	1.9	11:08:02	14:09:04
3/29/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190329_1	2.0	15:49:55	20:07:00
3/30/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190330_1	1.9	16:27:00	19:09:59
4/1/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190401_1	1.9	16:33:13	21:39:25
4/3/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190403_1	2.2	15:37:13	20:47:08
4/4/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190404_1	2.0	15:56:05	17:44:26
4/10/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190410_1	1.9	14:07:36	18:44:36
4/16/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190416_1	1.8	14:30:24	18:49:33
4/18/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190418_1	1.9	20:16:50	2:16:35
4/23/2019	Riegl VQ-1560i	S2222738	C-FVZM	20190423_1	1.5	14:33:20	16:02:45

Table 2: Collection Date Time by Mission

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
<b>B218</b>	Temporary	N/A	39 22 26.92902	75 04 29.05763	-12.970
<b>DENE</b>	CORS	DK4426	39 40 36.24960	75 44 34.82881	6.546
<b>NJAC</b>	SmartNet	N/A	39 23 15.96525	74 31 01.82398	-22.224
<b>NJBN</b>	SmartNet	N/A	39 25 21.72835	75 12 21.24760	-1.879
<b>NJCM</b>	CORS	DI3828	39 06 02.39693	74 48 10.42433	-25.313
<b>NJGC</b>	CORS	DF8717	39 46 52.79148	75 07 11.25002	-3.994
<b>NJHM</b>	SmartNet	N/A	39 38 01.75340	74 48 13.97488	10.874
<b>NJNT</b>	CORS	DK7749	40 12 33.61966	74 02 11.58975	-15.522
<b>NJOC</b>	CORS	DI1077	39 57 10.02328	74 11 36.59328	-8.184

Table 3: GNSS Reference Station Coordinates



Figure 2: GNSS Reference Stations

## 3.0 PROCESSING

### 3.1 Introduction

The ABGNSS/IMU data was post-processed using Applanix POSPac MMS software to create Smoothed Best Estimate Trajectory (SBET) file(s). The SBET was then combined with the laser range measurements in Riegl RiPROCESS software to produce the 3-dimensional coordinates resulting in an accurate set of Raw Point Cloud (RPC) mass points. These raw swath (\*.las) files are output in WGS84, UTM, Ellipsoid, Meters and transformed to the project Coordinate Reference System (CRS) upon ingest into GeoCue before project wide calibration.

The Riegl RiPROCESS pre-processing software created raw swath files with all return values. This multi-return information was processed and classified to obtain the required feature for delivery. All lidar data is processed using the ASPRS binary LAS format version 1.4. **Table 4** illustrates the achieved point cloud statistics.

Category	Value
Aggregate Total Points	62,293,810,662
Aggregate Nominal Pulse Spacing (m)	0.38
Aggregate Nominal Pulse Density (pls/m <sup>2</sup> )	7.0
Aggregate Nominal Pulse Spacing (ft)	1.24
Aggregate Nominal Pulse Density (pls/ft <sup>2</sup> )	0.7

Table 4: Point Cloud Statistics

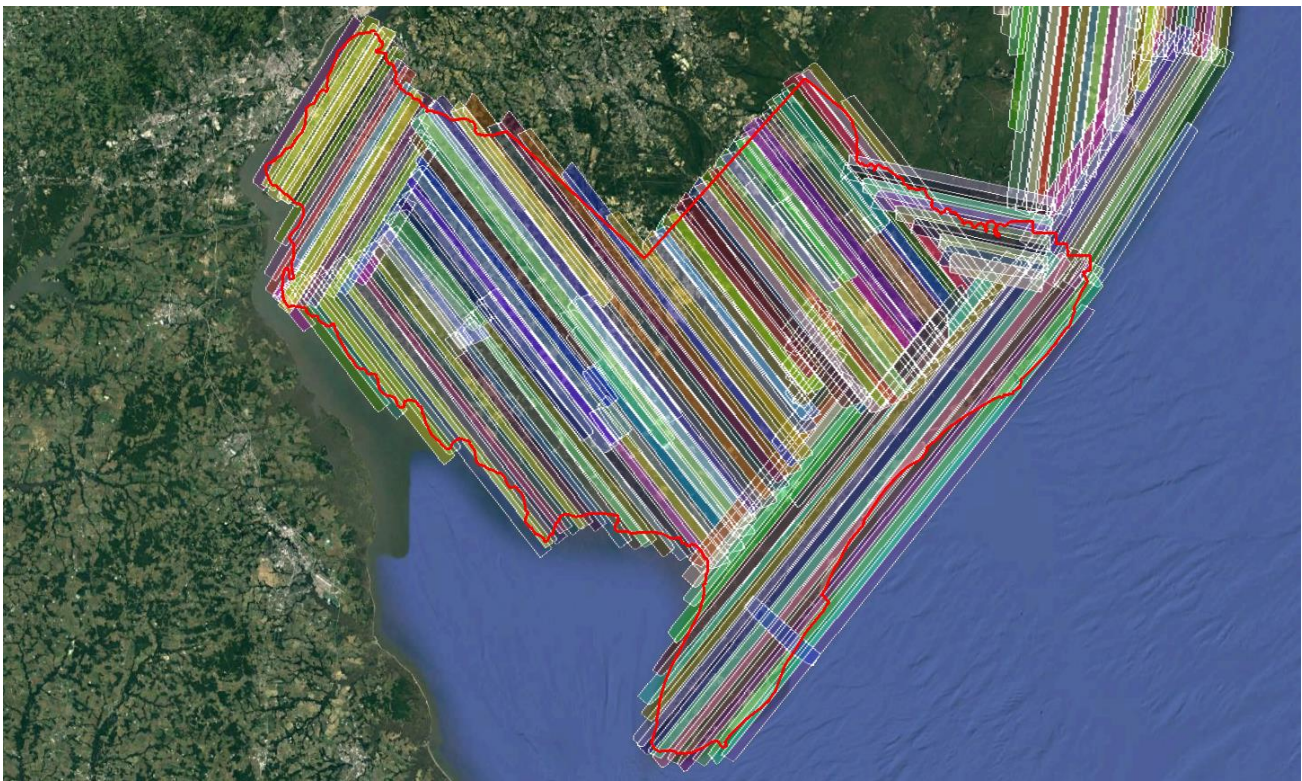


Figure 3: Raw Point Cloud Coverage

### 3.2 Coordinate Reference System

<b>Horizontal Datum:</b>	North American Datum of 1983 (2011)
<b>Projection:</b>	State Plane New Jersey (FIPS 2900)
<b>Vertical Datum:</b>	North American Vertical Datum of 1988
<b>Geoid Model:</b>	Geoid12B
<b>Units:</b>	U.S. Survey Feet

### 3.3 Calibration

Sanborn uses Riegl RiPROCESS and the latest boresight values to combine the processed SBET with the laser scan files to produce the lidar point cloud. The data is processed by mission and is output in ASPRS LASv1.4 Point Data Record Format (PDRF) 6 with 16bit linearly scaled intensities to the nearest 0.001 3D position. Each mission is produced in WGS84, UTM, Ellipsoid, Meters and transformed to the project CRS upon import into GeoCue.

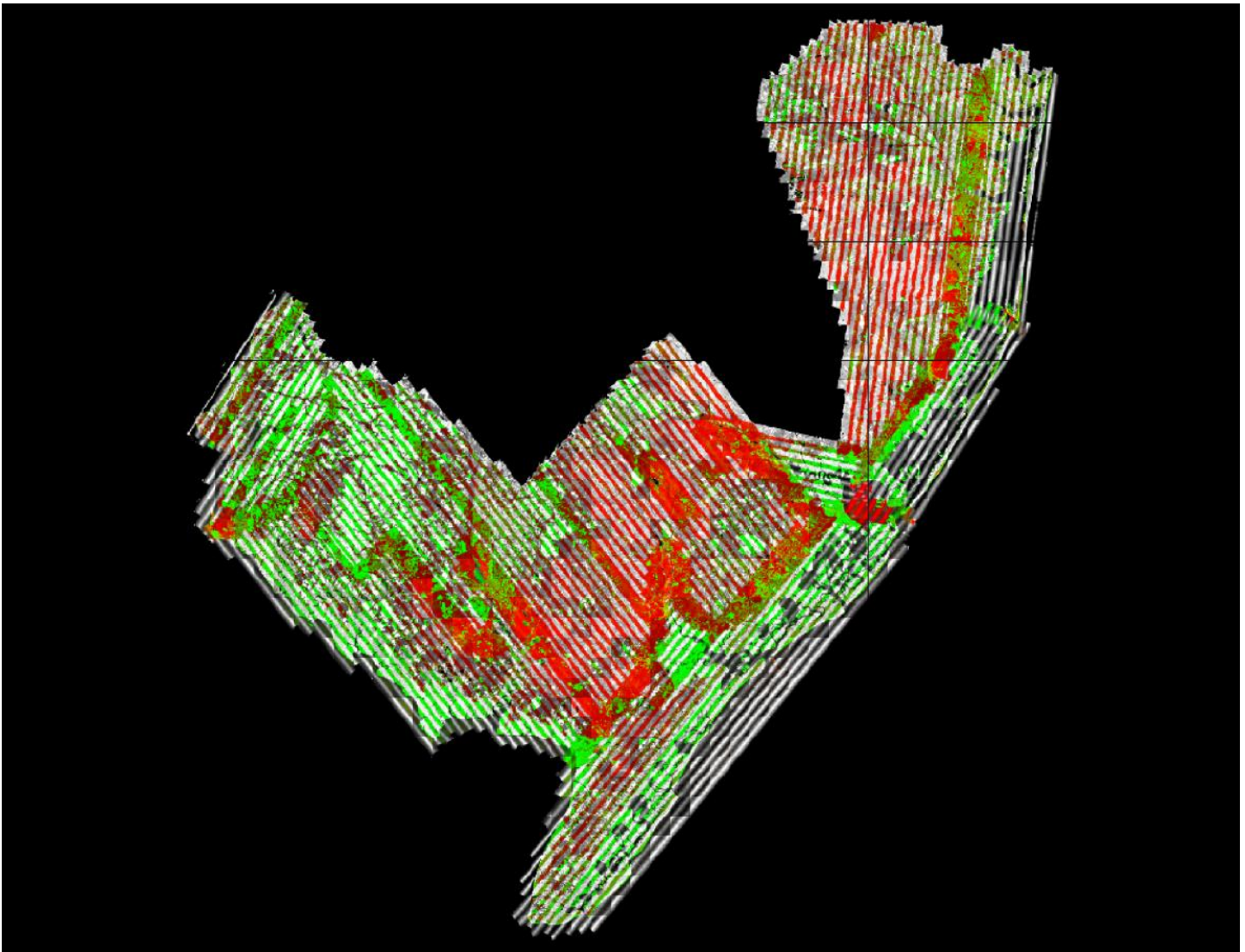
Each mission is imported into GeoCue where each individual flight line is assigned a unique flight line number. The SBET is cut per mission into TerraScan Trajectory files based on flight line number and timestamp to be utilized during the calibration process. The project area(s) are broken into logical blocks based on AOIs or predetermined delivery blocks and the individual flight lines are populated into calibration tile grids. These calibration tile grids are prepared for scanner, line, mission, block and eventual project wide calibration routines by first running point cloud filters to identify ground and building features to be used during TerraMatch processes.

After successful point cloud filters have been run on the calibration dataset TerraMatch is used to extract Tie Line Observations. TerraMatch Tie Lines are 3D vectors extracted from the lidar points cloud intended to reduce the overwhelming data size to a more manageable amount. Each Tie Line is extracted using a series of parameters designed to identify features such as a flat or sloping ground or roofline apexes that geospatially correlates to the same observation of an overlapping flight line. These collected 3D vectors are then utilized across multiple iterations to reduce the average offset from line to line, mission to mission, and block to block. TerraMatch Solutions are calculated to adjust Roll, Heading, Pitch, X, Y and Z in combination to reduce the Root Mean Square Deviation (RMSD<sub>r</sub> and RMSD<sub>z</sub>). These solutions are calculated, applied, and checked throughout the calibration process.

Sanborn takes advantage of both visual and statistical validation methodologies to review and ensure overlap consistency of the lidar data meets and/or exceeds project specifications. Differential Elevation (dZ) rasters are color ramp (Dark Green, Green, Yellow, Orange, Red) based visual representations produced to identify vertical offsets between flight lines. The dZ rasters are reviewed in their entirety for flight lines and areas that exceed the required RMSD<sub>z</sub>. Furthermore, an additional set of TerraMatch Tie Lines are produced after corrections are applied and a Tie Line Report is produced to assess the X, Y, and Z offset averages for each line and the project. This visual and statistical review guarantees the relative accuracy of the lidar dataset. **Table 5** outlines the relative accuracy requirements of the project. **Tables 6 – 9** are the relative accuracies achieved.

Category	Value
Smooth Surface Repeatability (ft)	≤0.197
Swath overlap difference, RMSD <sub>z</sub> (ft)	≤0.262
Swath overlap difference, Maximum (ft)	±0.525

Table 5: Relative Accuracy Requirements



No Data	0ft to 0.131ft	0.131ft to 0.262ft	0.262ft to 0.393ft	0.393ft to 0.524ft	> 0.524ft

Figure 4: dZ Rasters

Line	X	Y	Z	Line	X	Y	Z	Line	X	Y	Z
1	0.036	0.037	0.023	69	0.043	0.043	0.023	138	0.042	0.043	0.025
2	0.031	0.034	0.024	70	0.049	0.043	0.022	139	0.042	0.043	0.027
3	0.031	0.036	0.021	72	0.038	0.041	0.025	140	0.046	0.046	0.031
4	0.034	0.040	0.021	73	0.034	0.043	0.027	141	0.045	0.043	0.029
5	0.027	0.036	0.021	74	0.031	0.037	0.031	142	0.043	0.041	0.026
6	0.037	0.039	0.023	75	0.038	0.043	0.026	143	0.046	0.043	0.027
7	0.030	0.036	0.023	76	0.034	0.038	0.030	144	0.044	0.043	0.026
8	0.037	0.040	0.021	77	0.041	0.047	0.026	145	0.051	0.049	0.031
9	0.033	0.036	0.024	78	0.195	0.020	0.052	146	0.050	0.048	0.028
10	0.031	0.037	0.024	79	0.041	0.050	0.033	147	0.049	0.046	0.033
12	0.038	0.038	0.030	82	0.037	0.021	0.058	149	0.048	0.052	0.031
13	0.029	0.034	0.019	83	0.076	0.007	0.076	150	0.046	0.046	0.032
14	0.026	0.026	0.032	84	-	-	0.040	151	0.046	0.046	0.030
15	0.037	0.039	0.022	85	0.003	0.060	0.040	152	0.051	0.053	0.030



<b>16</b>	0.032	0.037	0.024	<b>86</b>	0.033	0.049	0.027	<b>153</b>	0.063	0.063	0.033
<b>17</b>	0.044	0.047	0.025	<b>87</b>	0.043	0.037	0.052	<b>154</b>	0.043	0.049	0.036
<b>18</b>	0.035	0.041	0.026	<b>88</b>	0.037	0.040	0.032	<b>155</b>	0.044	0.039	0.033
<b>19</b>	0.049	0.047	0.025	<b>89</b>	0.035	0.037	0.025	<b>156</b>	0.039	0.037	0.032
<b>20</b>	0.035	0.041	0.023	<b>90</b>	0.032	0.043	0.023	<b>157</b>	0.032	0.037	0.027
<b>21</b>	0.044	0.046	0.025	<b>91</b>	0.036	0.040	0.024	<b>158</b>	0.039	0.045	0.030
<b>22</b>	0.035	0.041	0.027	<b>92</b>	0.043	0.043	0.025	<b>159</b>	0.038	0.039	0.026
<b>23</b>	0.040	0.042	0.026	<b>93</b>	0.036	0.037	0.029	<b>160</b>	0.038	0.039	0.024
<b>24</b>	0.045	0.050	0.031	<b>94</b>	0.041	0.043	0.026	<b>161</b>	0.055	0.059	0.030
<b>26</b>	0.034	0.035	0.027	<b>95</b>	0.033	0.035	0.024	<b>162</b>	0.056	0.053	0.028
<b>27</b>	0.037	0.038	0.024	<b>96</b>	0.041	0.040	0.027	<b>163</b>	0.047	0.046	0.029
<b>29</b>	0.038	0.038	0.026	<b>97</b>	0.038	0.033	0.024	<b>164</b>	0.051	0.054	0.030
<b>30</b>	0.040	0.042	0.027	<b>98</b>	0.040	0.048	0.030	<b>165</b>	0.042	0.053	0.044
<b>31</b>	0.040	0.040	0.027	<b>101</b>	0.042	0.049	0.025	<b>166</b>	0.052	0.048	0.043
<b>32</b>	0.032	0.037	0.028	<b>102</b>	0.045	0.052	0.028	<b>167</b>	0.044	0.043	0.033
<b>33</b>	0.040	0.041	0.025	<b>103</b>	0.038	0.045	0.024	<b>168</b>	0.047	0.043	0.029
<b>34</b>	0.033	0.038	0.020	<b>104</b>	0.039	0.050	0.030	<b>169</b>	0.044	0.042	0.032
<b>35</b>	0.034	0.035	0.024	<b>105</b>	0.035	0.044	0.022	<b>173</b>	0.044	0.040	0.035
<b>36</b>	0.050	0.047	0.038	<b>106</b>	0.045	0.050	0.030	<b>174</b>	0.040	0.042	0.030
<b>37</b>	0.044	0.041	0.025	<b>108</b>	0.051	0.051	0.167	<b>175</b>	0.037	0.032	0.026
<b>38</b>	0.040	0.042	0.027	<b>109</b>	0.048	0.046	0.036	<b>176</b>	0.033	0.031	0.024
<b>39</b>	0.040	0.041	0.029	<b>110</b>	0.042	0.041	0.030	<b>177</b>	0.033	0.027	0.022
<b>40</b>	0.046	0.046	0.042	<b>111</b>	0.051	0.051	0.029	<b>178</b>	0.033	0.031	0.023
<b>41</b>	0.050	0.049	0.028	<b>112</b>	0.044	0.045	0.030	<b>179</b>	0.033	0.028	0.022
<b>44</b>	0.039	0.041	0.029	<b>113</b>	0.042	0.045	0.026	<b>180</b>	0.039	0.039	0.022
<b>45</b>	0.039	0.038	0.026	<b>114</b>	0.036	0.042	0.036	<b>181</b>	0.038	0.037	0.022
<b>46</b>	0.041	0.044	0.029	<b>115</b>	0.041	0.046	0.024	<b>182</b>	0.038	0.041	0.022
<b>48</b>	0.036	0.036	0.029	<b>117</b>	0.057	0.051	0.038	<b>183</b>	0.047	0.050	0.037
<b>49</b>	0.026	0.028	0.024	<b>118</b>	0.039	0.036	0.031	<b>184</b>	0.050	0.060	0.038
<b>50</b>	0.068	0.061	0.104	<b>119</b>	0.048	0.038	0.028	<b>185</b>	0.043	0.040	0.029
<b>52</b>	0.044	0.042	0.029	<b>120</b>	0.045	0.043	0.026	<b>186</b>	0.040	0.042	0.022
<b>53</b>	0.036	0.036	0.023	<b>121</b>	0.053	0.047	0.029	<b>187</b>	0.039	0.038	0.026
<b>54</b>	0.096	0.082	0.123	<b>122</b>	0.047	0.051	0.028	<b>188</b>	0.040	0.043	0.027
<b>56</b>	0.064	0.063	0.057	<b>123</b>	0.046	0.042	0.032	<b>189</b>	0.045	0.042	0.030
<b>57</b>	0.041	0.049	0.027	<b>124</b>	0.046	0.042	0.026	<b>190</b>	0.045	0.042	0.028
<b>58</b>	0.041	0.042	0.029	<b>126</b>	0.040	0.045	0.026	<b>191</b>	0.040	0.037	0.025
<b>59</b>	0.038	0.046	0.025	<b>127</b>	0.044	0.049	0.029	<b>192</b>	0.045	0.044	0.031
<b>60</b>	0.041	0.043	0.026	<b>128</b>	0.052	0.057	0.029	<b>193</b>	0.048	0.043	0.027
<b>61</b>	0.042	0.046	0.026	<b>129</b>	0.047	0.054	0.036	<b>194</b>	0.050	0.050	0.029
<b>62</b>	0.042	0.044	0.024	<b>130</b>	0.045	0.049	0.026	<b>195</b>	0.043	0.041	0.031
<b>63</b>	0.043	0.038	0.022	<b>131</b>	0.046	0.049	0.025	<b>196</b>	0.039	0.038	0.023
<b>64</b>	0.047	0.041	0.022	<b>133</b>	0.038	0.044	0.024	<b>198</b>	0.049	0.047	0.030
<b>65</b>	0.047	0.046	0.023	<b>134</b>	0.042	0.043	0.024	<b>199</b>	0.042	0.041	0.024
<b>66</b>	0.043	0.043	0.022	<b>135</b>	0.040	0.042	0.024	<b>200</b>	0.034	0.033	0.022
<b>67</b>	0.045	0.045	0.022	<b>136</b>	0.043	0.046	0.026	<b>201</b>	0.037	0.034	0.023
<b>68</b>	0.045	0.044	0.023	<b>137</b>	0.040	0.044	0.024				

Table 6: Average Magnitudes by Line (Feet)

Category	X	Y	Z
<b>Average Magnitude</b>	0.041	0.042	0.027
<b>RMS Values</b>	0.060	0.063	0.039
<b>Maximum Values</b>	0.497	0.496	0.500
<b>Observation Weight</b>	1904271.0	1904271.0	2089921.0

Table 7: Internal Observation Statistics (Feet)

Category	Mismatch
<b>Average 3D Mismatch</b>	0.07199
<b>Average XY Mismatch</b>	0.06560
<b>Average Z Mismatch</b>	0.02733

Table 8: Overall Relative Accuracy (Feet)

Category	Observations
<b>Section Lines</b>	75,066
<b>Roof Lines</b>	625,618

Table 9: Vector Observations

### 3.4 Lidar Classification

Lidar filtering was accomplished using GeoCue with TerraSolid processing and modeling software. The filtering process reclassifies all the data into classes with in the point cloud file based scheme. Once the data is classified, the entire dataset is reviewed and manually edited for anomalies that are outside the required guidelines of the product specification or contract requirements. This can include, but is not limited to, removing bridges, structures, filling culverts, and manually analyzing the bare-earth surface by classifying features that belong in non-extraneous classification codes. **Table 10** outlines the point classes leveraged in the lidar dataset.

Code	Description	Definition
<b>1</b>	Unclassified	Processed, but unclassified
<b>2</b>	Ground	Bare-earth surface
<b>7</b>	Low Noise	Erroneous returns below bare-earth surface
<b>9</b>	Water	Hydrologically identified water surface points
<b>17</b>	Bridge Decks	Structure carrying a means of transit of higher
<b>18</b>	High Noise	Erroneous atmospheric returns above bare-earth
<b>20</b>	Ignored Ground	Bare-earth points near breaklines excluded from
<b>Flag</b>	Overlap	Overage points lying within overlapping areas of two or more swaths
<b>Flag</b>	Withheld	Outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath

Table 10: Lidar Classification Scheme

### 3.5 Accuracy Assessment

The lidar dataset was evaluated using a total of one hundred and forty-two (142) check points (82 NVA + 62 VVA). The end result provided an RMSEz that fell within project specifications. Please see the **Attachment A** for the full Vertical Accuracy Report and the project **Metadata** for an in-depth accuracy assessment. **Table 11** outlines the absolute accuracy requirements of the project. **Table 12** shows high level statistics and mean errors for the area processed by Sanborn.

Category	Value
RMSEz (ft)	≤0.328
@ 95-percent confidence level (ft)	≤0.984

Table 11: Absolute Accuracy Requirements

Broad Land Cover Type	# of Points	RMSEz	95% Confidence Level	95th Percentile
NVA of Point Cloud	56	0.122	0.238	
NVA of Bare Earth	56	0.122	0.240	
NVA of DEM	56	0.117	0.229	
VVA of Bare Earth	41	0.124		0.249
VVA of DEM	41	0.119		0.227

Table 12: Vertical Accuracy Assessment of Check Points (Feet)

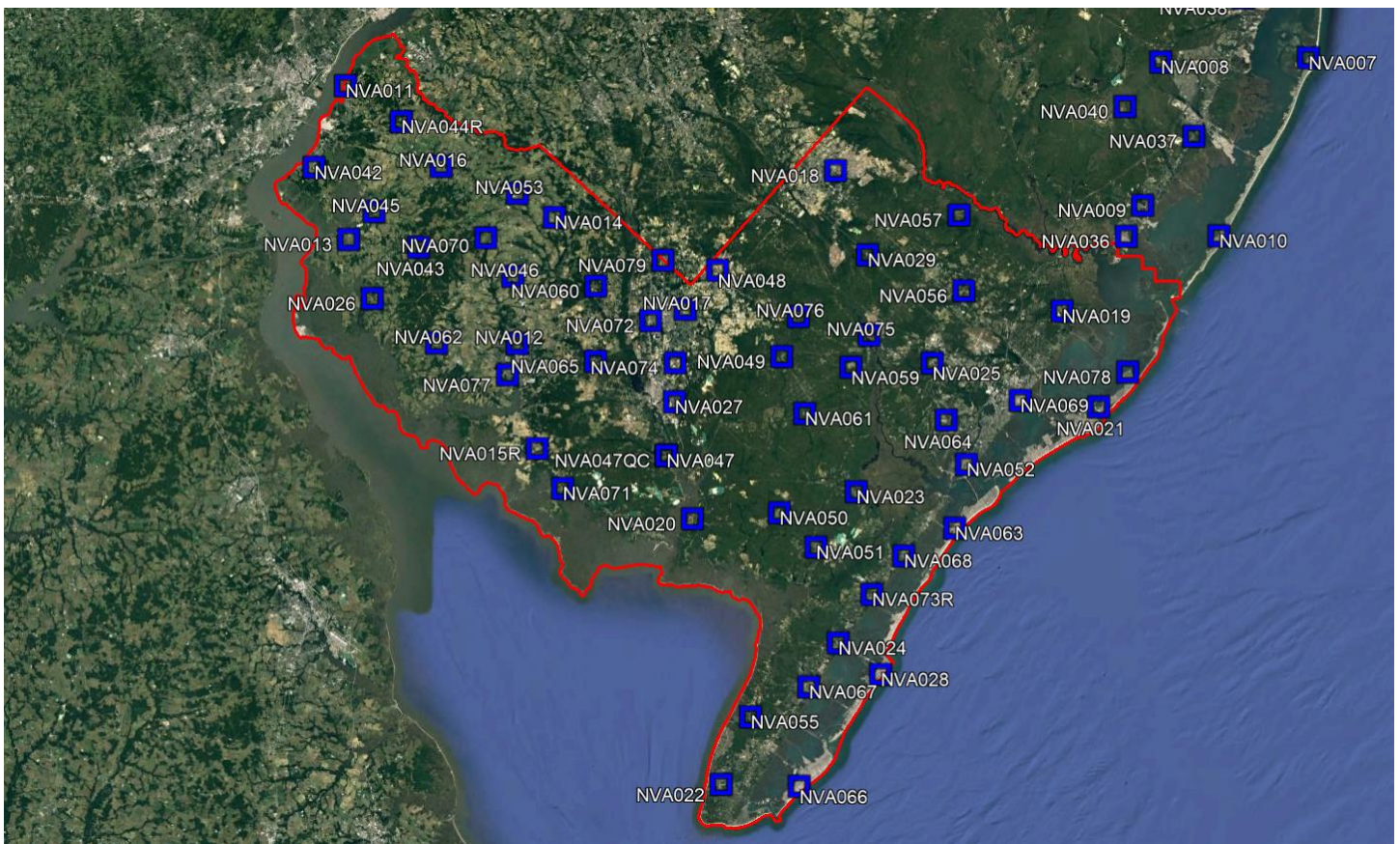


Figure 5: Non-vegetated Check Point Distribution



## 4.0 PRODUCT GENERATION

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Once the lidar surface was finalized and manually QC'd for anomalies, the required deliverables were then generated and/or organized. The following products were generated using the final coordinate system as defined in the contract, and provided in section 4.0 of this report.

### **Classified Point Cloud**

The Classified Point Cloud, containing all returns, is delivered in LASv1.4 (\*.las) format and meets project specifications. The Classified Point Cloud contains file names referencing the tile index.

### **Bare-Earth Digital Terrain Model**

32-bit ERDAS Imagine (\*.img) 2 ft elevation rasters were created from the bare-earth points in the processed lidar dataset. Each pixel contains an elevation value interpolated from the lidar.

### **Intensity Rasters**

8-bit ERDAS Imagine (\*.img) 2 ft intensity rasters were created from the first-return points in the processed lidar dataset.

### **Other Deliverables**

Vertical Accuracy Report  
Metadata

A final QC process was undertaken to validate all deliverables for the project. Prior to release of data for delivery, Sanborn's Quality control/quality assurance department reviews the data and then releases it for delivery.