To: Alex Nemeth

From: Stephen DiCicco

Date: 7/22/2011

Subject: RAMPP West Virginia LiDAR QA/QC: Coal River Delivery

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RAMPP has been tasked and funded by FEMA Region III to perform LiDAR quality assurance and quality control checks for a 7,889 mi^2 portion of southern West Virginia. The evaluation will assess the usability of the LiDAR data in supporting the West Virginia Department of Environmental Protection Division of Mining and Reclamation. In addition, the report will comment on the LiDAR's conformance to FEMA's "Procedure Memorandum No. 61 – Standards for LiDAR and Other High Quality Digital Topography." The following describes the QA/QC procedure and results for the first delivery of West Virginia LiDAR. The delivery includes 2,144 LAS tiles covering 1,907 mi^2 in southwest West Virginia. The dataset is referred to as the Coal River delivery.

The data is classified using a 3 class scheme: class 1 – unclassified, class 2 - ground, and class 7 - noise. The horizontal coordinate system for the project is NAD83 UTM zone 17N, the vertical datum used is NAVD88; horizontal and vertical units are in meters. The QA/QC process involved macro and micro completeness and LiDAR quality checks as well as a quantitative absolute vertical accuracy assessment.

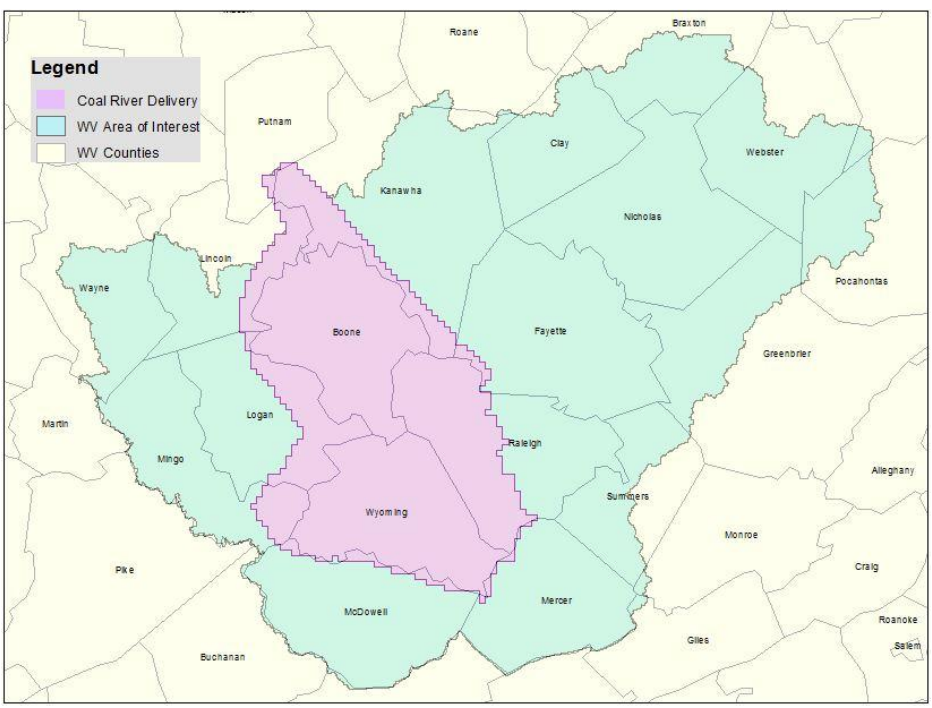

Figure 1 - West Virginia area of interest and Coal River delivery.

The Coal River LiDAR is generally good and meets most specifications as described in the RAMPP Statement of Work including absolute vertical accuracy requirements. However, there are opportunities for improvement by the LiDAR provider, some of which are significant. Several inconsistencies and errors were identified that should be addressed to ensure the highest quality data product. Most significantly, several areas that contain apparent re-flights (based on provided flight trajectories) contain relative accuracy or other offsets of up to one meter. Although the offsets seem to be localized, they exceed relative accuracy error tolerance specifications as described in both the project scope of work and PM61. In addition, the offsets create visible discrepancies in models created from ground points, including flight line ridges and noise. Overlap between all LAS tiles is another significant error. Other anomalies include corn rows, significant artifacts left classified in the ground, misclassification of ground points to unclassified and prevalent minor misclassification of ground points into noise.

In addition, a formal acquisition report including flight records and calibration details was not provided with the LiDAR and therefore could not be reviewed. This information is required for the final project delivery to WVDEP and would have been helpful for the QA process.

Completeness

Figure 2 shows a close up view of the Coal River delivery overlaid on the West Virginia area of interest. The northernmost portion of Coal River tiles boarders the area of interest but falls short in four places. These gaps range from 0.1 to 0.2 mi^2. Though not an error, trajectories show that LiDAR was flown for these gaps. Processing these portions with this delivery, if they are to be processed, would have been most efficient.

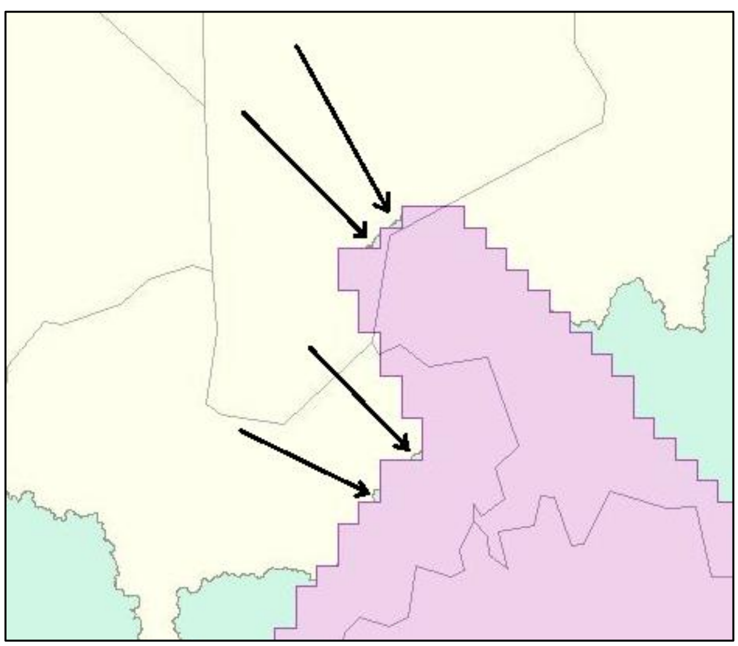

Figure 2- Northern portion of the Coal River delivery. Four small portions of the greater West Virginia project area are not covered by Coal River tiles.

100 percent of the tiles were visually reviewed for completeness and large anomalies. Delta-Z ortho images made from the LAS tiles using the full point cloud were used to check for voids in the data. Acceptable voids include those over water bodies, where specular reflection off the water allows the sensor to receive no return. No significant data voids were found.

Data Parameters

A statistical analysis was performed to assess minimum and maximum x, y and z values, point classification statistics and other LAS tile parameters. As specified by project guidelines, the LAS files should conform to ASPRS LAS Specification 1.2 or 1.3, and to the technical specifications outlined in the scope of work. The following inconstancies were noted:

- By request, RAMPP renamed the tiles according to West Virginia's statewide tiling system. The TILE_ID field now shows the correct tile name as required by the project scope of work.
- GEOID09, the latest geoid model, was used to reference the vertical coordinate system for all tiles. While this conforms to the ASPRS LAS Specification 1.2, the scope of work states that heights will be referenced according to GEOID03.
- Tiles are 1.5 by 1.5 km in size. This conforms to the tile scheme provided by WVDEP; however the scope of work states that tiles should 3 by 3 km in size.
- The minimum and maximum flight times are expressed in Julian dates rather than in modified GPS time.
- Minimum and maximum scan angles as great as 30 degrees off nadir were reported for several tiles. The WVDEP Spring Report states that the OPTECH ALTM-3100C LiDAR system used for acquisition is capable of scan angles up to only 25 degrees off nadir. RAMPP recommends scan angles not exceed 20 degrees from nadir.

Macro Level Review

All LAS tiles were reviewed on a macro level for large inconsistencies. The LAS tiles were used to create Delta-Z ortho images which measure and display the relative accuracy between flight lines (how well one flight line vertically matches an overlapping flight line) through colorization. Three significant issues were found after analyzing Delta-Z ortho images and data statistics: flight line offsets, inconsistent editing, and overlap in the LAS tiles.

Inconsistent Classification

The total percentage of points classified to ground varies significantly from tile to tile in some cases. Tiles C21499 and C21500 are neighboring tiles with similar topography that appear significantly different in Delta-Z ortho images. Tile C21499 contains 30% ground points while C21500 contains 11%

ground points. The tiles are not classified consistently. This inconsistent classification occurs in several areas, particularly along the edges of re-flight trajectories. Additionally, localized pockets of tiles with low ground point percentages that are also caused by inconsistent editing were noted. Tile C22728 and its surrounding tiles is an example.

Ground models for select tiles where inconsistent editing has occurred (including the three mentioned above) were created and examined for point density specifications, inconsistencies and anomalies. The nominal point spacing requirement of 2 meters or less was met, and ground models looked clean and consistent from tile to tile. The inconsistent editing should be noted but does not have a noticeable impact on the quality of the LiDAR.

LAS Overlap

The LAS tiles overlap each other and the West Virginia tile scheme by approximately 10 meters on all sides. Figure 3 shows LAS tile C25425 converted to an ESRI multipoint file and overlaid on the project tile scheme. The overlapping portion of points which extends past the tile boundary and is duplicated by the neighboring tiles is measured at 10.0 m in length. This is not consistent with the scope of work which specifies seamless tiles. As discussed subsequently in the LiDAR QA/QC section of this report, the LAS overlap also causes classification errors along tile seams. The tiles should be trimmed and edges should be inspected for remaining artifacts.

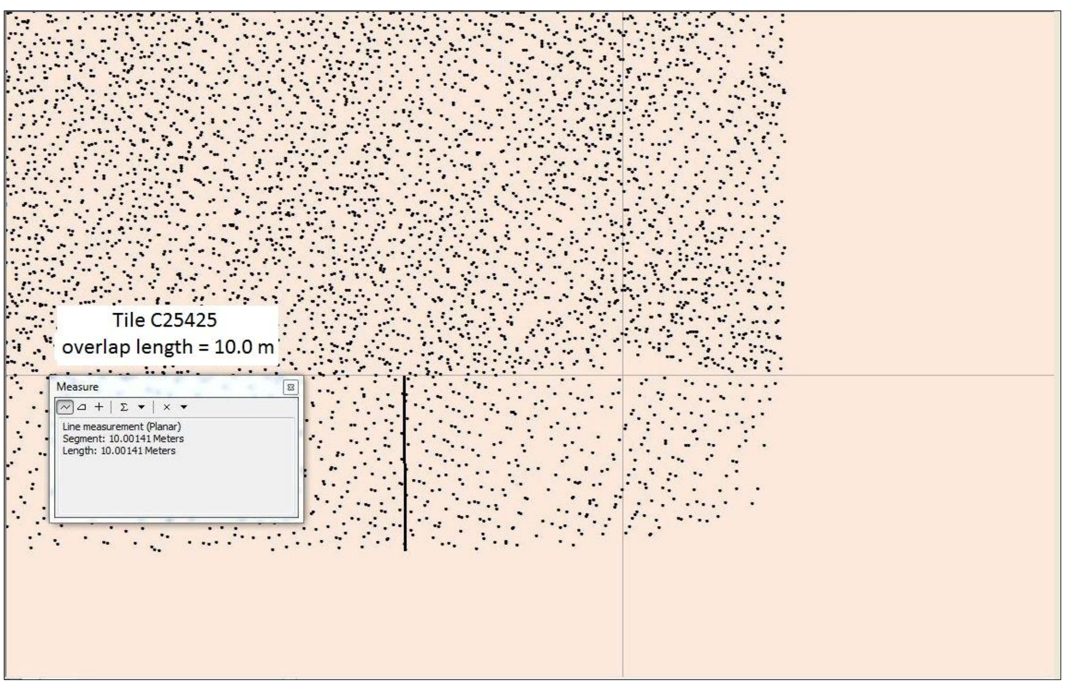

Figure 3- The LiDAR points exceed the tile boundary by approximately 10 m.

Flight Line Offsets

Flight trajectories for the Coal River delivery show sections of dense overlapping flight lines which are assumed to be re-flights. Several flight line offsets were detected in areas where multiple flight lines overlap; primarily the re-flight areas. Figure 4 shows a profile from tile C21975 colored by flight source identification. Pink and purple points (which appear similar) are from flight lines s_173 and s_374 respectively. Yellow points are from flight line s_121. Flight line s_121 is up to 1 m lower than the other two.

In some cases, like in Figure 4 the flight line offset is "classified out" meaning the lower of the two lines was classified to ground and the upper to unclassified. This may affect the absolute vertical accuracy of the data if tested in this location. Additionally, noise and flight line ridges which can be attributed to the flight line offsets are seen in the ground models.

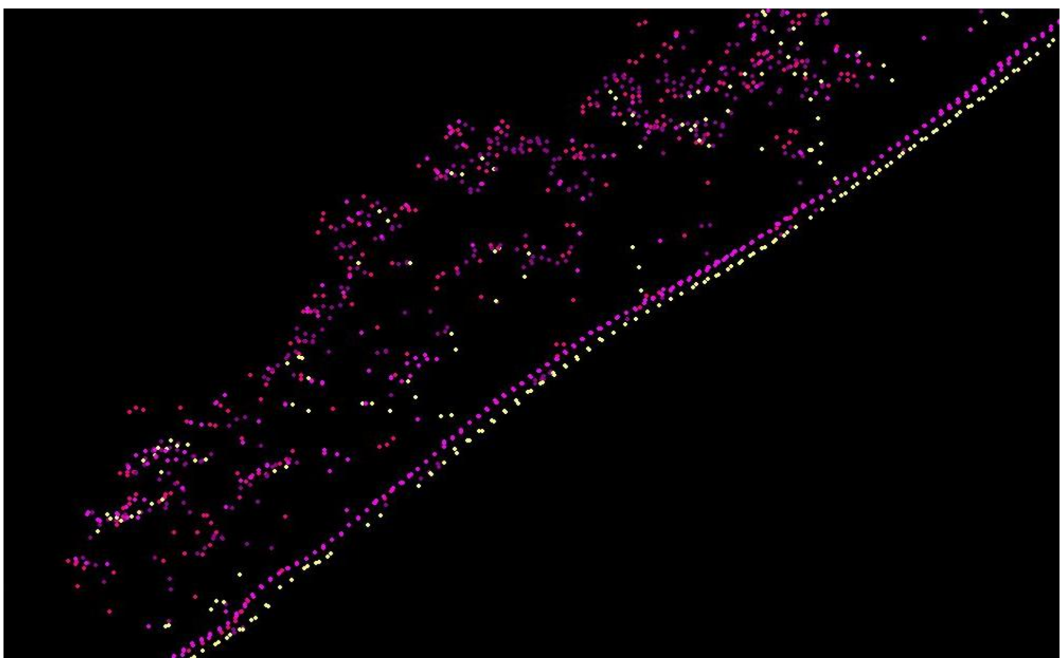

Figure 4 - A profile from LAS tile C21975 colored by flight source ID. A flight line offset which measures up to 1 m is visible.

Figure 5 shows a mosaic of Delta-Z ortho images created using only first return points. Overlaid are the flight line trajectories. The red tiles are an indication that a flight line offset may exist. Areas containing the greatest portion of red clearly correspond to re-fights. RAMPP recommends all tiles containing re-flight trajectories be examined and corrected for flight line offsets. Some flight lines along which offsets are known to exist include:

s_363	s_158	s_169	s_148	s_414	s_151	s_378	s_121	s_375
s_364	s_159	s_559	s_149	s_152	s_111	s_122	s_380	

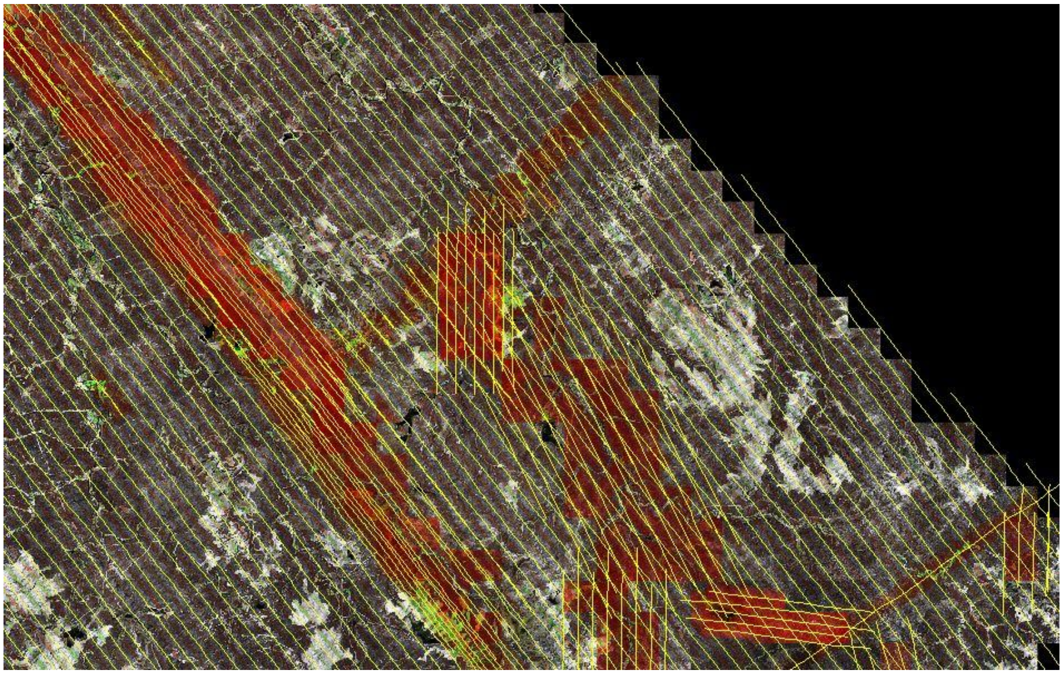

Figure 5 - Delta-Z ortho images for several West Virginia tiles with flight line trajectories shown in yellow. Red indicates a flight line offset may exist. Areas containing the greatest amount of red correspond to re-flight and trajectories.

Temporal Changes

Also noted within tiles covered by re-flights were actual changes in the ground which occurred between flight dates. **Error! Reference source not found.** shows a profile from LAS tile C23751 colored by flight source identification where mining has altered the shape of the ground significantly. In these cases, the more recent depiction of the ground should be consistently classified. Classifying flight lines depicting different ground conditions together contributes to flight line ridges and noise and will add uncertainty to the vertical accuracy calculation. RAMPP recommends checking any tiles with a large span of time between its start and end flight date for significant temporal changes.

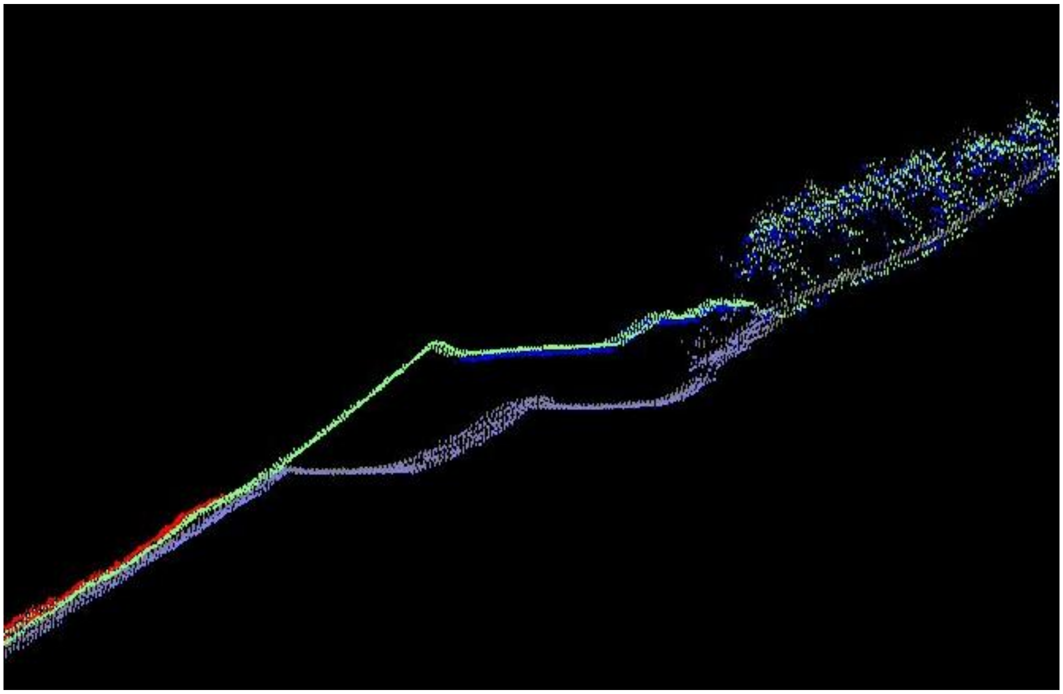

Figure 6- A profile from LAS tile C23751 colored by flight source ID. The landscape has changed significantly between flight dates.

Vertical Accuracy Assessment

An important aspect of the LiDAR Quality Control process is a test of the absolute vertical accuracy of the LiDAR against independently measured ground control points. The Coal River delivery of West Virginia LiDAR passes the absolute vertical accuracy testing requirements specified by PM61 and the West Virginia statement of work.

Field Survey

Ground surveys are used to establish vertical accuracy of LiDAR data sets. RAMPP was tasked with providing LiDAR survey checkpoints for the greater West Virginia FEMA project area. The survey, performed between March and May of 2011, consisted of 321 checkpoints divided between 4 geographic blocks and uses horizontal projection NAD83/CORS96 Epoch 2002 and vertical datum NAVD88, geoid09, with vertical units of US Survey feet. The Coal River LiDAR delivery intersects 98 of these checkpoints. Table 2 lists the four land cover categories surveyed and used for the Coal River vertical accuracy assessment. RAMPP reviewed all survey data to ensure that the checkpoints are adequately distributed over the Coal River project area and flight trajectories, that the minimum point per land type criterion is met, that checkpoints are a good representation of their land cover category, and that checkpoints exhibit good checkpoint placement. Figure 8 shows all checkpoints over the FEMA area of interest and the Coal River delivery bounds. Figure 9 shows the distribution of checkpoints within the Coal River delivery by land cover type.

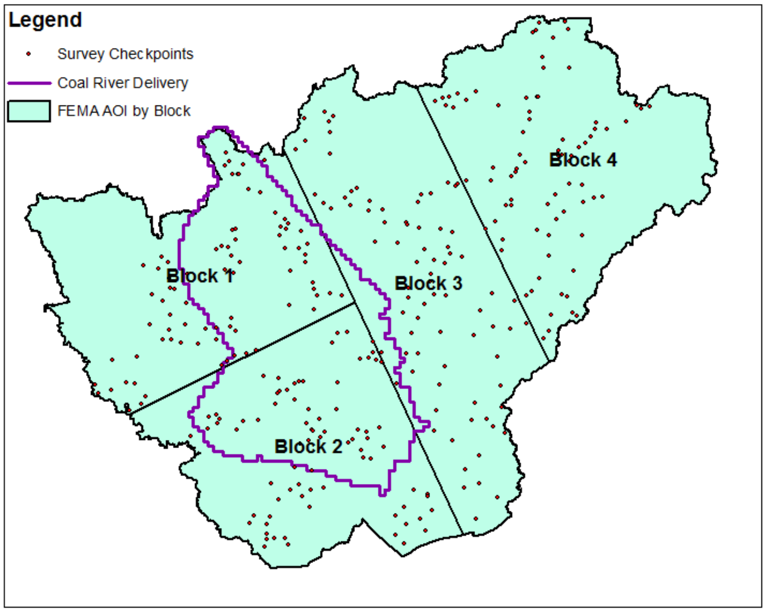

Figure 7- The survey checkpoints and block locations with the Coal River delivery outlined.

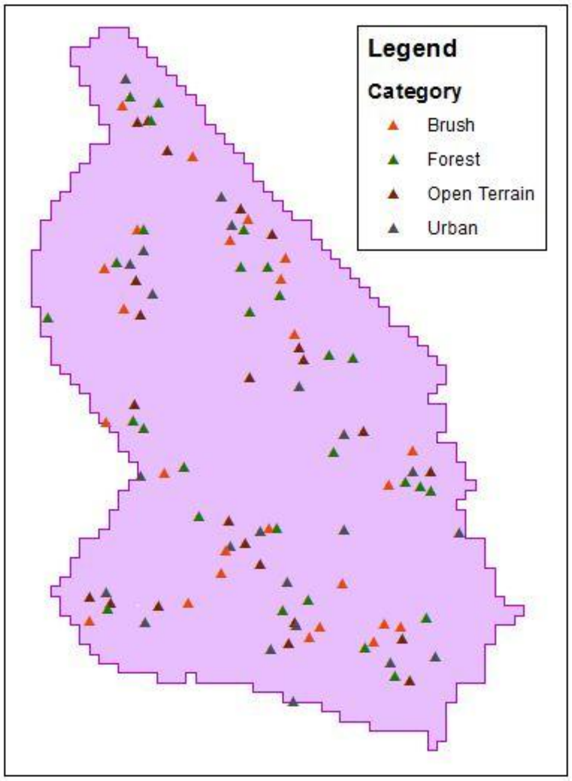

Figure 8- Checkpoint by land cover type for the Coal River LiDAR delivery.

Vertical Accuracy Results

The vertical accuracy of the data was tested by comparing ground elevations derived from the LiDAR to independently measured survey checkpoint elevations. As defined by the National Standard for Spatial Data Accuracy, vertical accuracy is reported at the 95% confidence level using the Root Mean Square Error between checkpoint elevations and the ground elevation of the LiDAR at the corresponding x and y location and equals $RMSE_Z$ * 1.9600. The standard assumption that errors follow a normal distribution is made.

Vertical accuracy was calculated for each land cover type and for the consolidated checkpoints. The consolidated $RMSE_Z$ is 0.118 m which meets the specified 0.185 m. Thus Coal River LiDAR has been tested to meet 0.209 m consolidated vertical accuracy at 95% confidence level. This meets PM61 specifications of 0.363 m. As per the West Virginia Scope of work, the data is also tested to meet 0.210 m fundamental vertical accuracy; meeting the specified 0.300 m. Table 1 describes vertical accuracy by land cover type and for the consolidated checkpoints. Table 2 highlights the $RMSE_Z$ statistics.

Though the data passes absolute vertical accuracy requirements, the results do not negate the fact that the LiDAR contains significant relative vertical accuracy errors. While checkpoint distribution meets standards, checkpoints do not necessarily intersect areas of relative vertical offsets, meaning it cannot be assumed that the absolute accuracy results apply uniformly.

Table 1- FVA, CVA, and SVA at 95% confidence level.

Land Cover Category	Number of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.300 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.363 m	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.363 m
Consolidated	97		0.209	
Open Terrain	23	0.210		0.187
Brush	25			0.206
Forest	27			0.175
Urban	22			0.217

Table 2- Descriptive Statistics for Coal River LiDAR vertical accuracy calculations by land cover category.

100 % of Totals	RMSE (m)	Mean (m)	Median (m)	Skew	StdDev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.118	-0.042	-0.041	-0.433	0.111	97	-0.444	0.200
Open Terrain	0.107	-0.035	-0.037	-0.170	0.104	23	-0.286	0.185
Brush	0.139	-0.029	-0.032	-0.838	0.138	25	-0.444	0.200
Forest	0.092	-0.028	-0.046	-0.208	0.090	27	-0.215	0.106
Urban	0.133	-0.081	-0.057	-0.065	0.107	22	-0.300	0.147

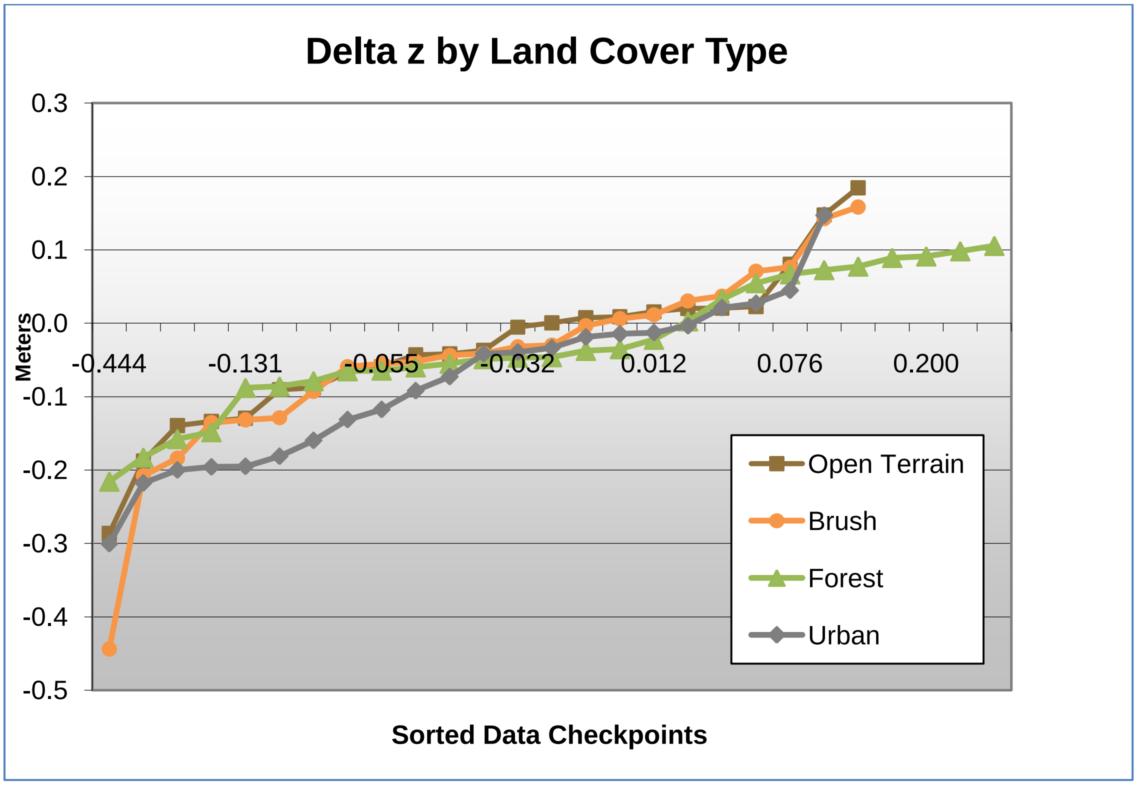

Figure 9 - Coal River checkpoint delta z values by land cover type.

LiDAR QA/QC

Five percent of the Coal River data was examined on a micro level for artifacts, misclassification, aggressive classification, voids, sensor anomalies, consistency and point density fulfillment. The 108 tiles were selected based on urban and developed areas, areas designated priority A or AE by FEMA Q3 flood data and areas containing several overlapping flight lines including the re-flight areas. Figure 10 shows the QA/QC selection.

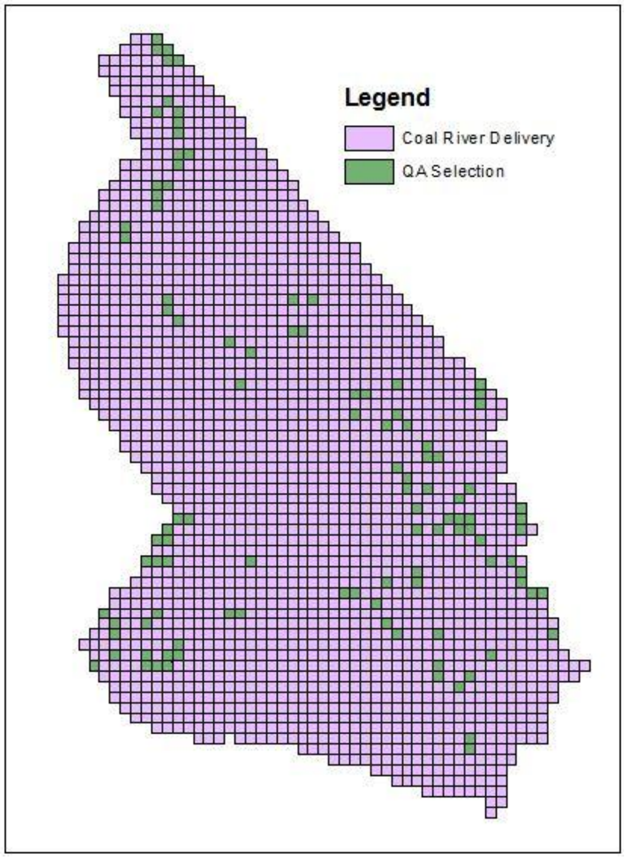

Figure 10 – The 108 tiles selected for a micro level QA/QC review.

The quality of the LiDAR was generally good; however, some errors were noted that should be addressed. These include effects of the tile overlap, artifacts, divots, misclassification, flight line rides, noise, and cornrows.

Tile Overlap Effects

Overlap in the tiles resulted in inconsistent editing along tile edges. Generally the main 1.5 km portion of the tile was classified while the overlapping portion was not. This left a line of artifacts along the edge of the tile ground models. Figure 11 depicts the line of artifacts left in the ground density model of tile C22728. All tiles contained this error along all or some of their edges. The tiles should be clipped then reviewed for remaining artifacts along seams.

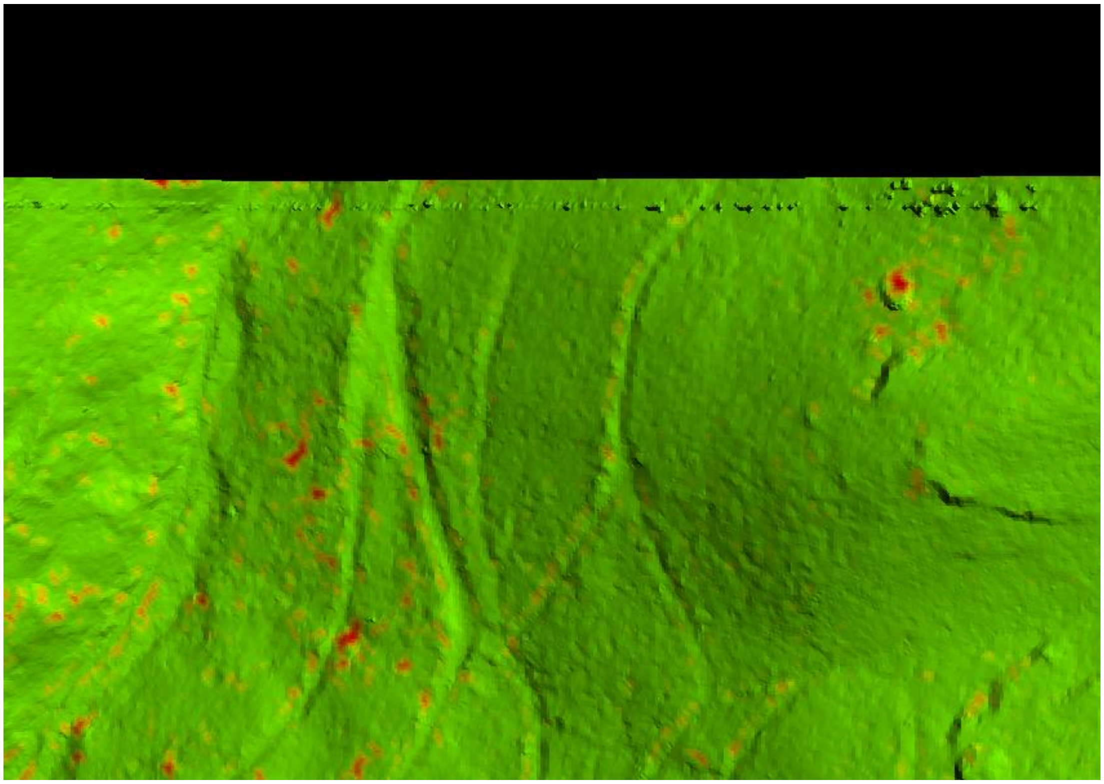

Figure 11- Tile C22728 shows a line of vegetation artifacts along its overlapping edge.

In very limited cases, a ridge appeared in the overlapping portion of the tiles. This signifies a change in ground elevation from one tile to the next and is likely a result of flight line offsets. Figure 12 shows a ridge in the overlapping corner of tile C23751. This tile was used previously to depict a significant temporal change and is known to contain flight line offsets.

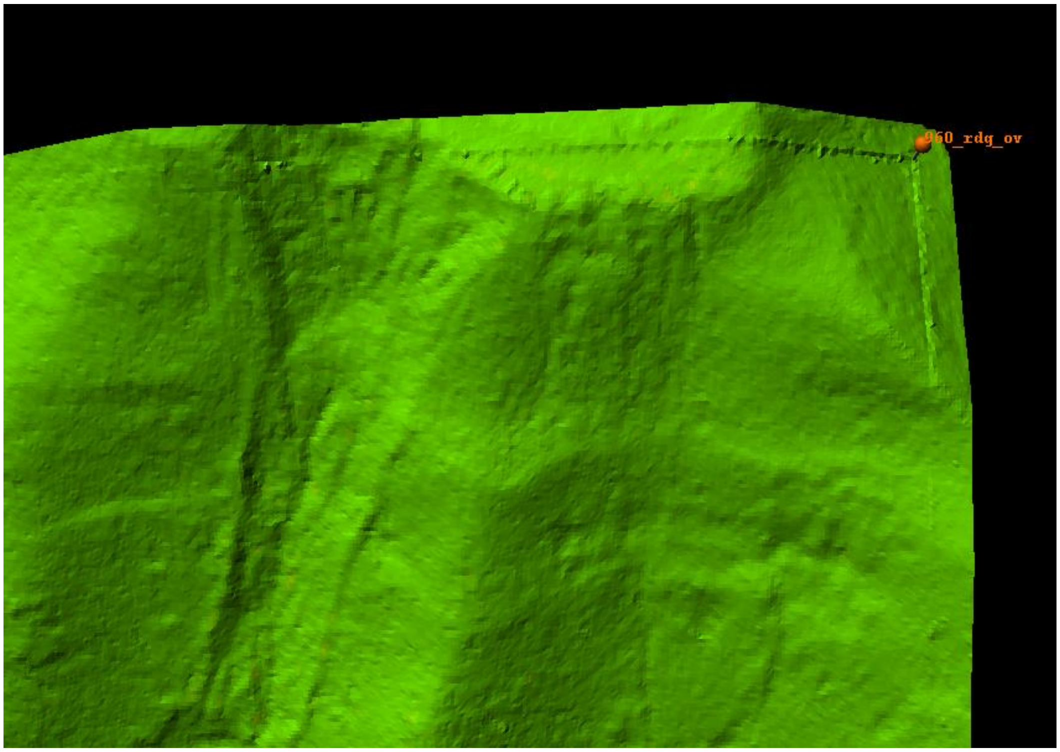

Figure 12 – A ridge formed by the overlap between tile C23751 and its neighbors. This signifies a flight line offset.

In limited cases, a void was present on one more tile edges. These are not actual data voids but are a product of the tile overlap. No data voids were found in the full point cloud Delta-Z ortho images meaning these voids will be filled by the overlap of neighboring tiles. Figure 13 depicts one such void in red for the ground density model of tile C24832.

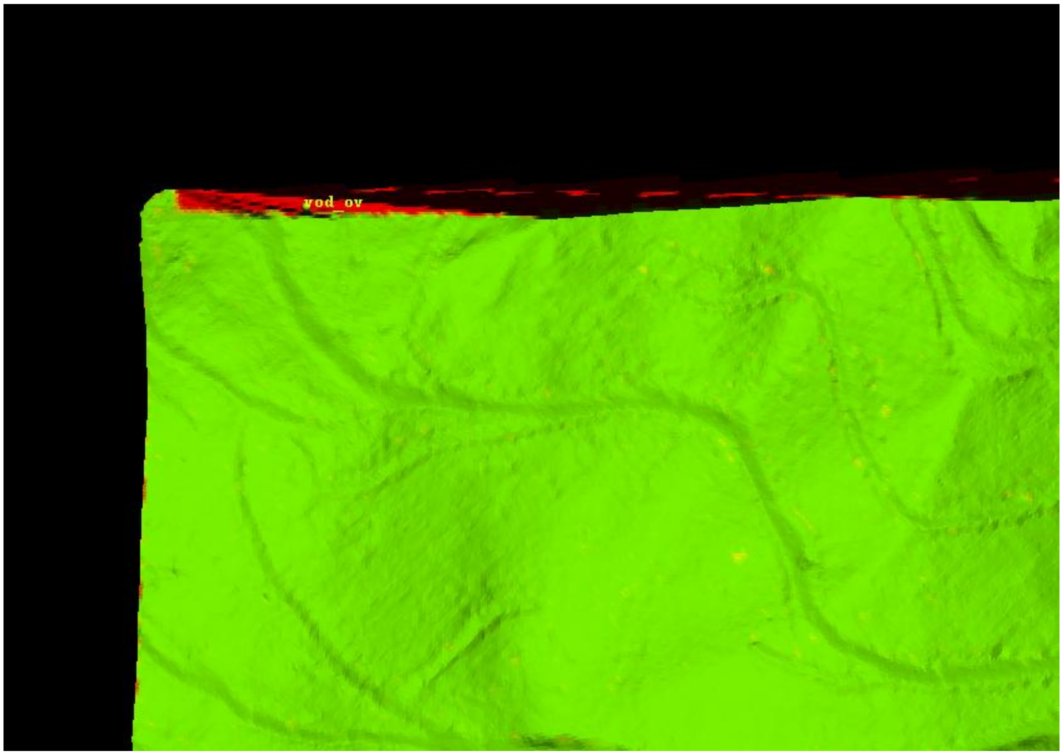

Figure 13 – A data void on the overlapping edge of tile C24832. This will be filled by the overlap of the tile above.

Artifacts

Typical of most LiDAR, several small artifacts, mostly vegetation, were left classified into ground. These do not significantly affect the ground model and do not compromise the quality of the LiDAR.

A small portion of artifacts including buildings, bridges and vegetation which exceed the specified maximum of 20 cm and will impact the ground model were left classified into ground. Significant artifacts were marked according to their type. Large artifacts should be reclassified. Figure 14 shows a large building left classified in ground for tile C18075. This was the largest artifact found in the five percent review.

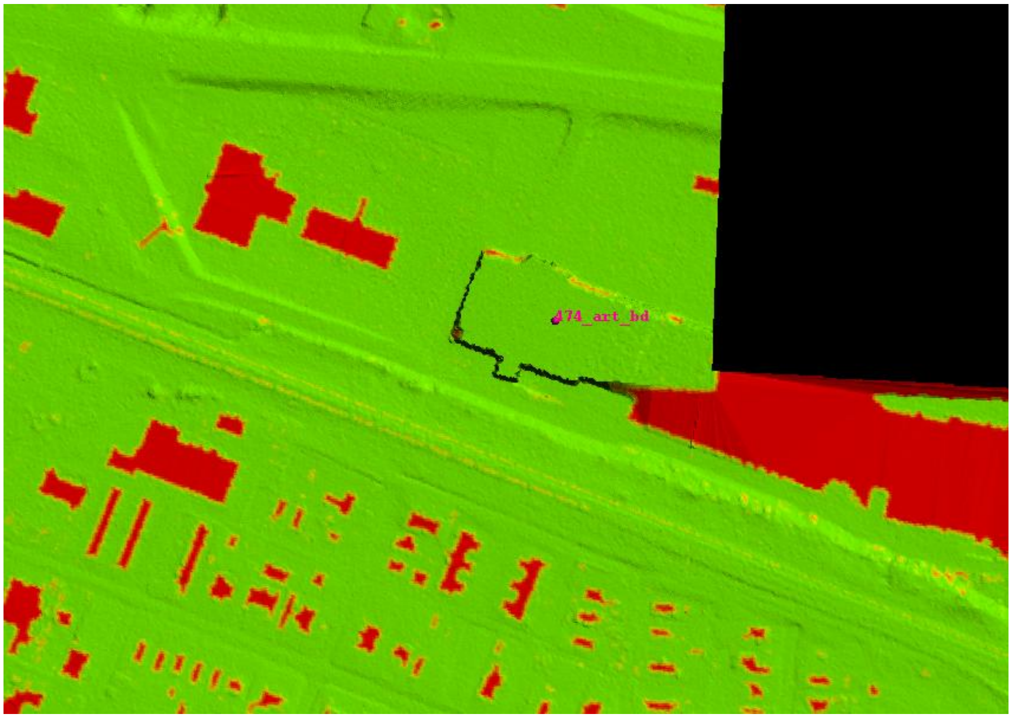

Figure 14 – A large building artifact left in the ground density model of tile C18075.

Divots

Also typical of LiDAR, several small divots were noted in the ground models. These do not have a significant effect on the ground model. Only significant divots were marked. Figure 15 shows an example of a significant divot. Few large divots were identified.

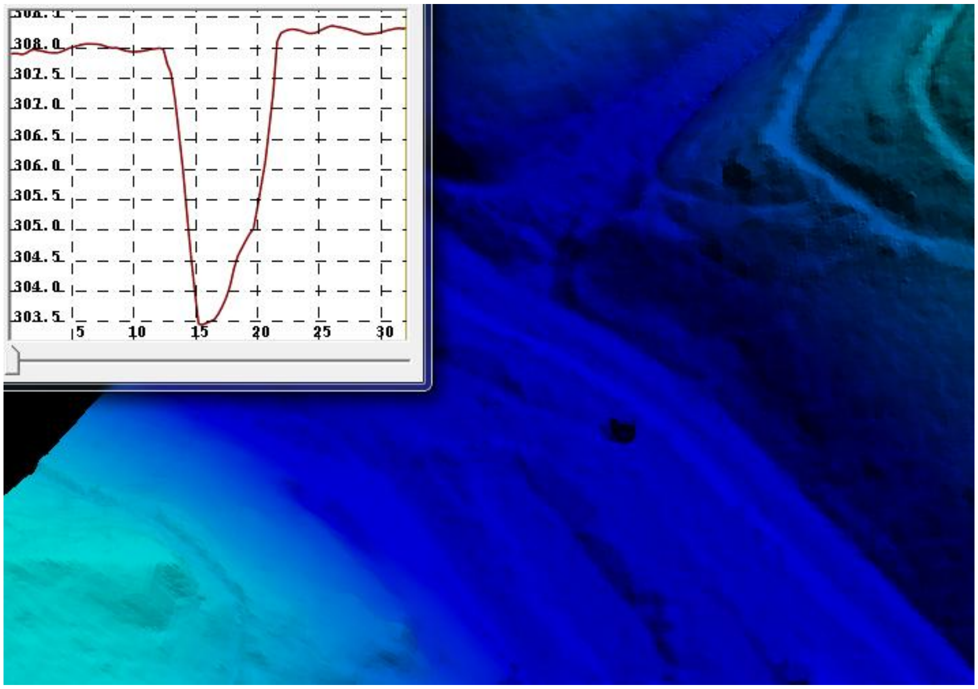

Figure 15 – A large divot in the ground elevation model of tile C23321.

Misclassification

Both major and minor misclassifications of ground points were observed. Two large circular holes were noted where ground point were misclassified into class 1. Figure 16 shows this misclassification as it appears in the ground density model. Figure 17 shows a profile of the LiDAR points colored by classification. Ground points are shown in pink, unclassified points in yellow. The mistaken classification of points in the circular area is clear.

There are several occurrences of misclassifying points to class 7, noise, in the data. Several areas of low point density which appeared to be caused by poor LiDAR penetration actually contain clear ground points which are misclassified into noise. Figure 18 shows LAS points colored by classification for a forested area where ground points are misclassified to noise.

Some aggressive editing where resolvable ground points were misclassified either to unclassified or to noise was observed. This was generally minor.

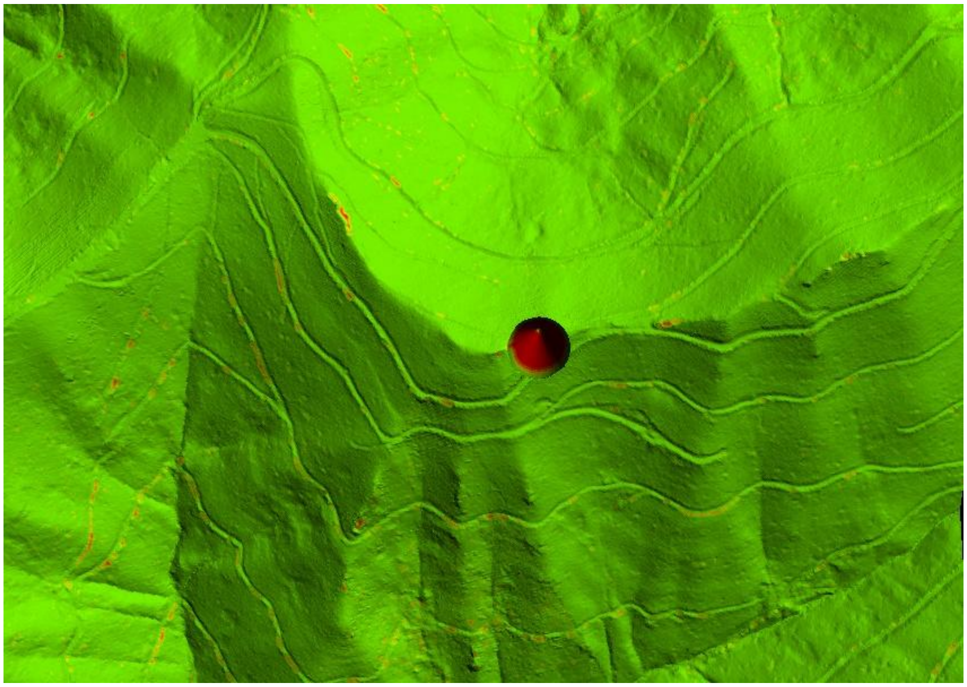

Figure 16 – An unnatural hole in the ground model of tile C24029 caused by misclassification of ground points to unclassified.

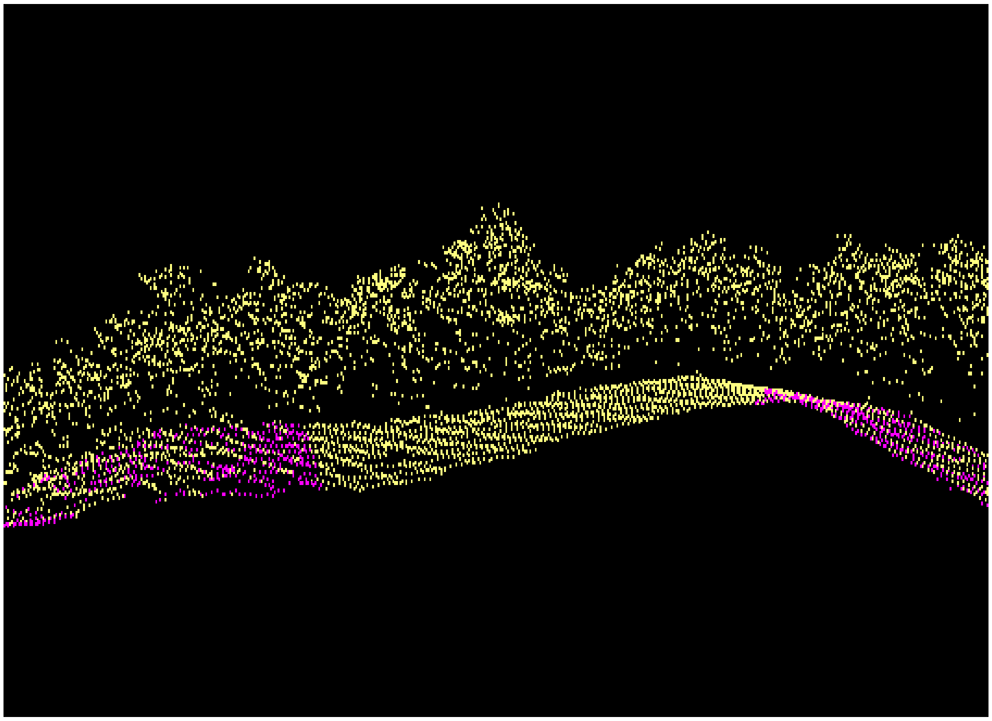

Figure 17 – A profile of the misclassification in LAS tile C24029. Ground points are shown in are pink, unclassified points are in yellow.

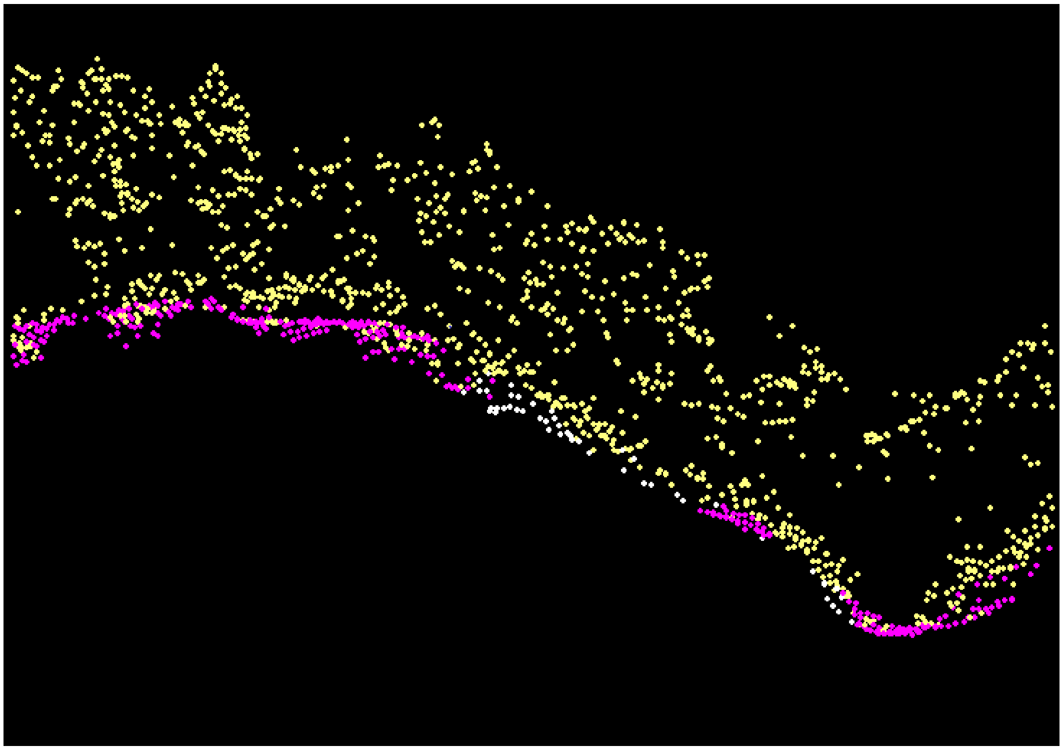

Figure 18 – A profile from LAS tile C26638 colored by classification showing misclassification of ground points to noise. Pink is ground; yellow is unclassified and white is noise. Misclassified noise points towards the center of the profile are clearly in line with the ground.

Flight Line Ridges

As previously mentioned, a limited number of flight line ridges were detected in the QA sample. These occurred in areas previously determined to contain flight line offsets. Figure 19 shows a flight line ridge present in tile C21975. While ridges are generally linear like that in Figure 19, other flight line ridges in the data were affected by inconsistent classification and have varying patterns.

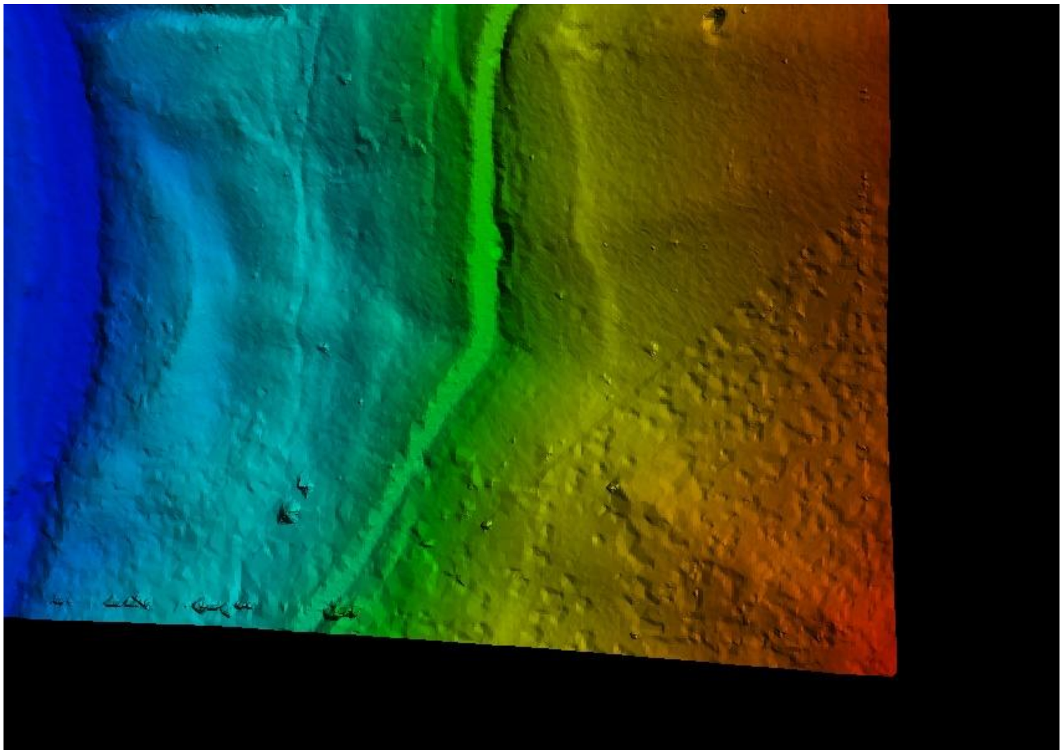

Figure 19 – A flight line ridge in tile C21975.

Flight Line Ridges

Several tiles contained noise over 20 cm. Often one side of a slope appears noisy while the other side does not. Figure 20 shows an example of this. Some noise corresponds with flight line ridges and is a result of classifying points to ground from flight lines that are offset.

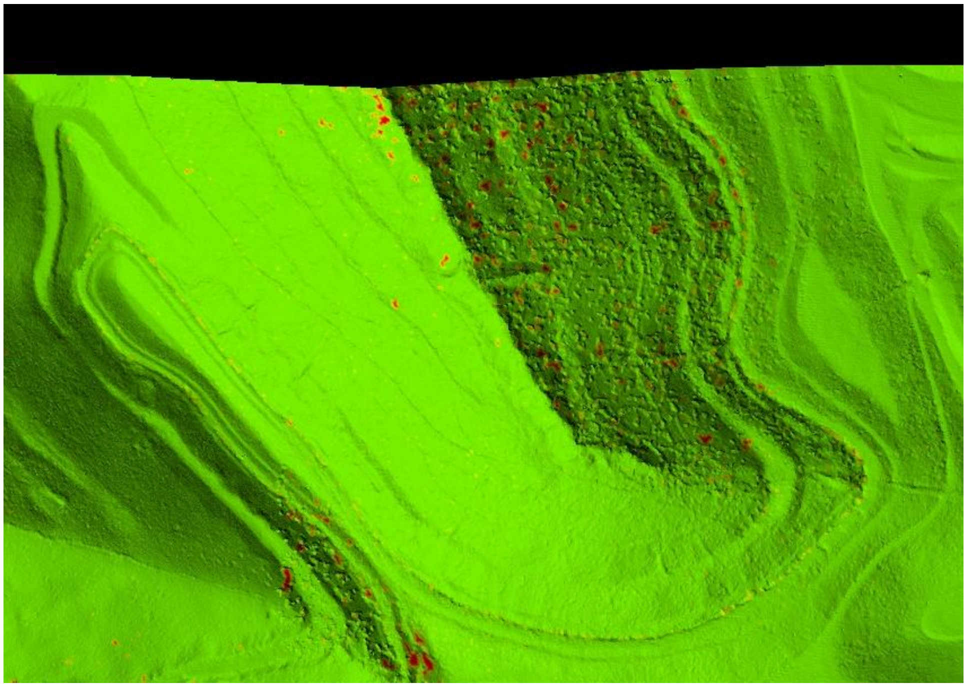

Figure 20 – Noise is present on the left side of both hills. Tile C22432.

Corn Rows

Corn rows are present in the LiDAR data. These occur when overlapping scan lines are slightly offset from each other. For portions of a scan line, typically the outer edges, point returns take on an alternating pattern as they become less frequent. Typically, LiDAR points from an overlapping flight line are added, and the pattern is undetectable. If the two fight lines do not match vertically, however, the points will not mesh and a false pattern of alternating higher and lower relief will appear in the ground model. This affect is known as corn rows.

The West Virginia project specifications require a vertical error of 30 cm or less at the 95% confidence level. Based on this specification, corn rows exceeding 15 cm are considered errors which require reprocessing. No cornrows which could be reliably measured as exceeding the 15 cm tolerance were found in the data. Some instances of cornrows which average between 10 and 14 cm were observed. These were noted in LiDAR QA assessment and, while they do not strictly require adjustments, it is recommended that these corn rows be corrected both to improve the quality of the ground model and to identify possible flight line offsets. Figure 18 shows corn rows averaging 10 cm.

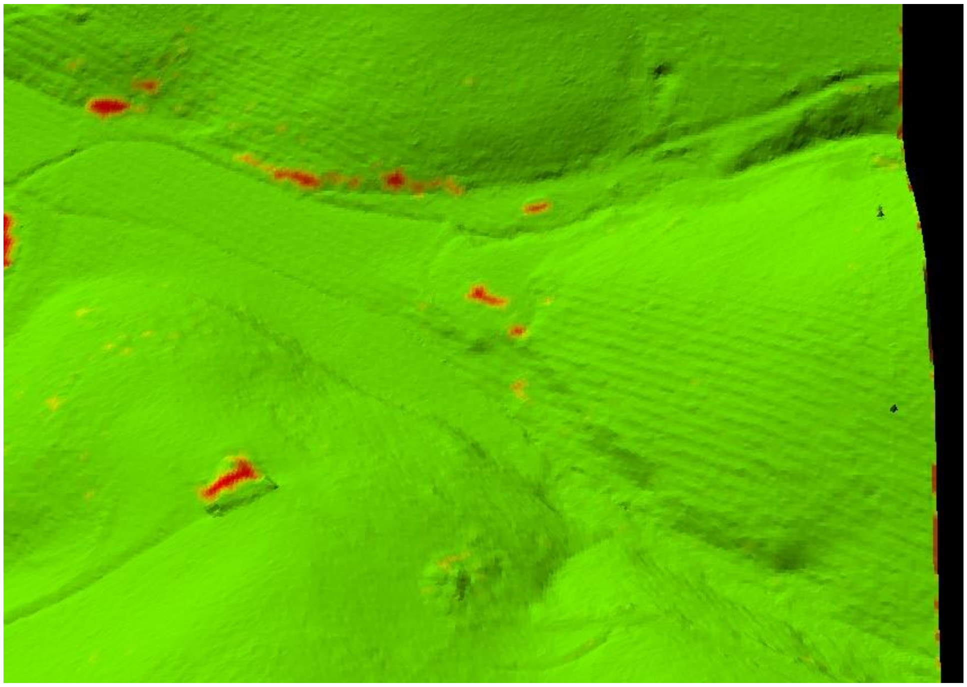

Figure 21 – Negligible corn rows in tile C25077 averaging 10 cm. Correcting these corn rows is recommended but not required.

One additional inconsistency was noted. For a small number of cases, often bordering an area of cornrows, point density was low enough that the scanner pattern was clear in the ground density model. This cannot be easily fixed, however it does not greatly impact the ground model. Figure shows the linear pattern present in the ground density model for tile C27958. The yellow lines represent a scarcity of LiDAR points.

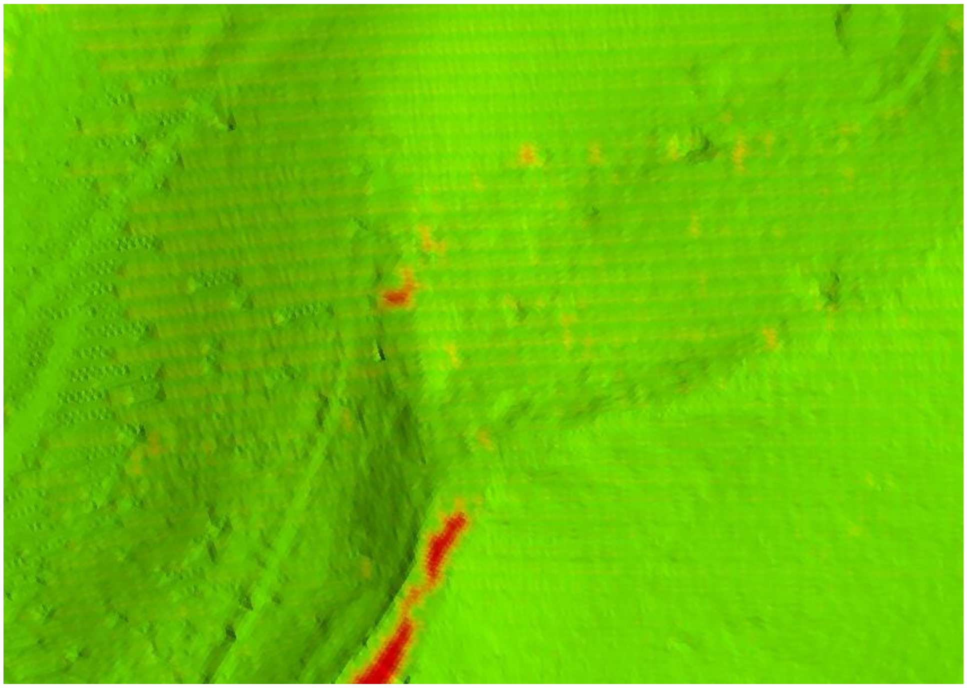

Figure 19 – Points are sparse enough that the scanner pattern becomes visible. This is noted for QA assessment, but is not expected to be resolved.

An ESRI shapefile containing markers with error codes and explanations was created for the 108 sampled tiles. Errors are prioritized into priority level 1 or 2. Priority 1 calls include artifacts or inconsistencies relating to the overlap in LAS tiles, full building artifacts, full bridge artifacts and any artifact large enough to impact the ground model as well as major misclassifications, large divots, flight line ridges and noise. Priority 1 calls should be fixed by the data provider. Priority 2 calls include cornrows, minor misclassifications and partial building or other artifacts. Fixing these calls would improve the overall quality of the data.

Conclusions

After a limited quality review of the Coal River delivery block of the RAMPP West Virginia task order, RAMPP concludes that the data appears acceptable from an aesthetic point of view, however it contains some issues that may require additional processing that will improve the overall quality of the data, ensure relative accuracy between flight lines and remove minor inconsistencies identified throughout the dataset. The flight line offsets are the most significant error present in the LiDAR. The data meets requirements for absolute vertical accuracy; however this does not negate errors caused by flight line offsets. RAMPP feels that relative vertical accuracy is in some applications as important or even more important than absolute vertical accuracy, and for that reason, it is recommended that the flight line offsets be corrected. Resolving this issue should also address some of the noise and ridges noted in the LiDAR ground models. Other issues which must be addressed are the overlap in the LAS tiles, large misclassifications of the ground surface, and large structures left in the ground. Once these issues are rectified, the LiDAR will be of high quality and will be useful in fulfilling the needs of the West Virginia Department of Environmental Protection and the Division of Mining and Reclamation.