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Date: 12/14/2012

Subject: RAMPP West Virginia LiDAR QA/QC: Third Delivery

RAMPP has been tasked and funded by FEMA Region III to perform LiDAR quality assurance and quality control checks for a ~3,165km^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 adherence to FEMA's "Procedure Memorandum No. 61 – Standards for LiDAR and Other High Quality Digital Topography." This delivery included 2,176 LAS tiles. The dataset is referred to as the Third Delivery.

The data are 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 Third Delivery extent.

There are significant opportunities for quality improvement by the LiDAR provider, including reclassification of non-ground artifacts such as vegetation, buildings, bridges and divots. These issues are described in detail below.

Completeness & Macro-Level Review

A 100% completeness check was performed on the Third Delivery LiDAR dataset. This section describes the steps taken to review the dataset at a macro level. The macro level completeness check was conducted to identify errors in data inventory (missing or corrupted files), major flaws such as data voids or calibration errors, and LAS header errors such as missing projection or extent information.

Delivery Inventory

A file inventory was conducted based on the tile grid provided by WVNRAC. **The delivered LAS contained 3 files that were not included in the tile grid.** Tiles C022013 and C22013 appear to be in the same location although they were not included in the delivered tile grid. The tile grid should be adjusted to include one of these LAS with the proper naming convention. Tile C14983 is on the outer extent of the tile grid but since no project boundary was delivered the tile should be added to the tile grid.

Delta-Z Ortho Image Review

The LiDAR was loaded into GeoCue LiDAR processing software to create Delta-Z ortho images. The Delta-Z ortho image is created by measuring the elevation difference between ground points from overlapping flight lines and applying a color-coded scale to identify areas of the data that have poor calibration. The Delta-Z ortho image has the LiDAR intensity value blended with the Delta-Z color value so the ground surface and features can be identified. This allows the analyst to identify errors in the intensity values, the flight line calibration, and missing data all at the same time. Figure 2 shows a sample Delta-Z ortho image from the Third Delivery dataset.

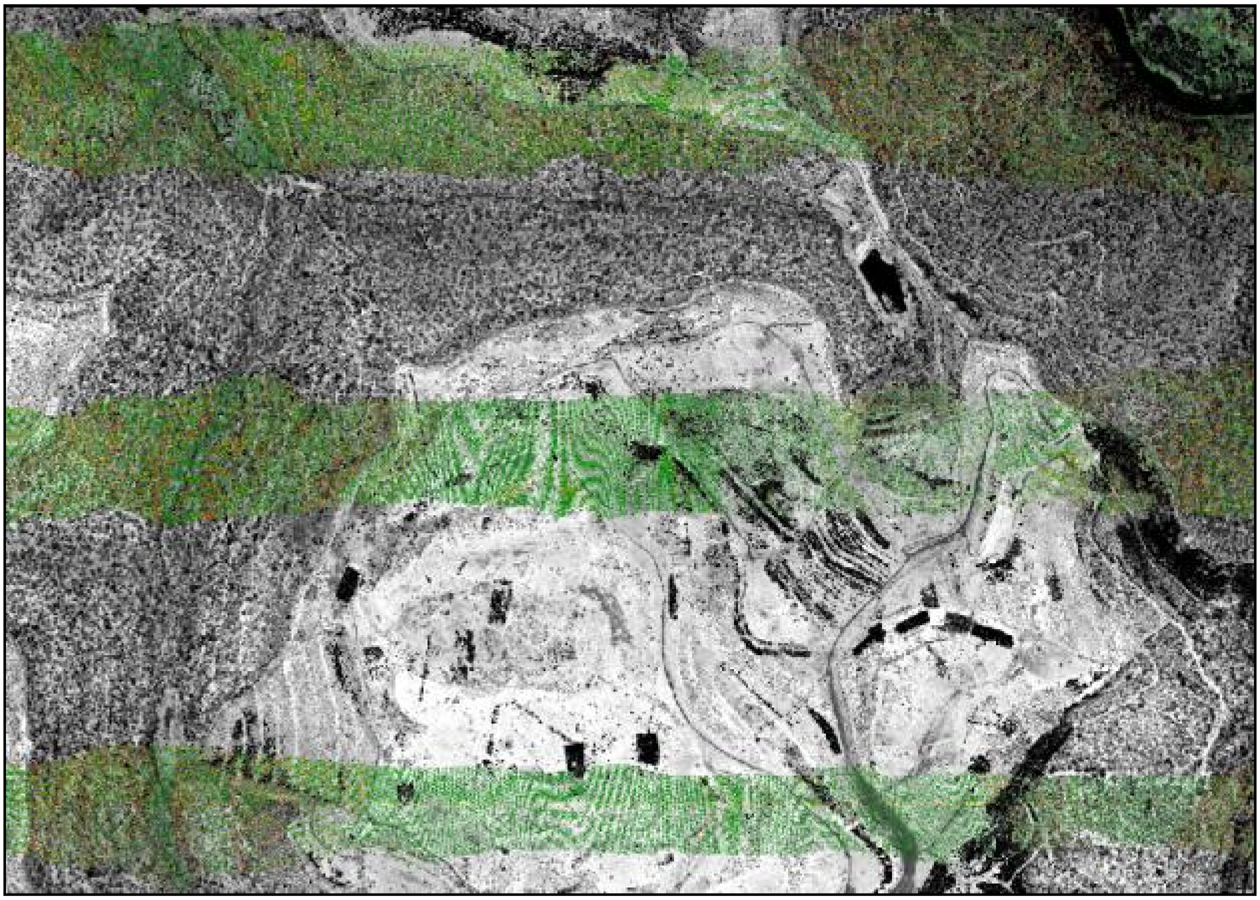

Figure 2 - Delta-Z ortho image of tile C16767.

In the image above, the pixel size was 2 meters and the error gradient was 0.15 meters, meaning the green pixels have an error value of less than 0.15 meters, the yellow pixels have an error of 0.15-0.30 meters, and the red pixels have an error of greater than 0.30 meters. Due to the extremely high relief in the project area many of the pixels showing large elevation errors are not a reliable measure of possible calibration issues. In this situation a higher priority was placed on the low-relief areas, such as the areas around the river and along the roads. The image above is a good example of the quality of the Third Delivery dataset, where a low delta-Z error is prevalent in the low-relief areas around the river and along the roads.

LAS Header Review

A LAS parser was used to read the LAS Header information to identify errors in the extent or projection information. The following errors were noted:

- No GUID or projection information was populated in the header. According to LAS 1.2 specification, the LAS Header must be populated with the GUID 1-4 fields and the projection information.
    - This error is likely caused by the TerraScan software that was used to process the data. When the LAS file is loaded into TerraScan, the software strips the header information. The header information must be reapplied, either in TerraScan or in another software suite, such as GeoCue.
- The LAS tiles contain overlap of approximately 10 meters on all sides. While the overlap is often applied for DEM generation, it will cause problems during GeoTerrain generation and should be removed if a GeoTerrain production is planned.

Summary of Completeness & Macro-Level Review

During the 100% completeness and inventory check, a number of issues were identified that should be corrected prior to using the data, including missing data, missing information in the LAS Header, and overlapping LAS tiles. A Delta-Z ortho review was conducted and the data has a generally good calibration of overlapping flight lines.

Detailed Micro-Level Review

According to the RAMPP Statement of Work, a 5% micro-level visual review was conducted on the LiDAR data to identify qualitative errors in the dataset. A total of 122 tiles were selected using a random tile selection algorithm for the review. Many of these errors are easily fixed, such as vegetation artifacts and aggressive classification.

The table below shows the breakline of the call types:

Table 1 - Breakdown of edit calls made in the 5% visual review of the Third Delivery LAS.

Call Type	Number of Occurrences
Aggressive Misclassification	81
Artifact	200
Divot	8
Culvert Misclassification	12
Tile Overlap Effect	104
Total	**405**

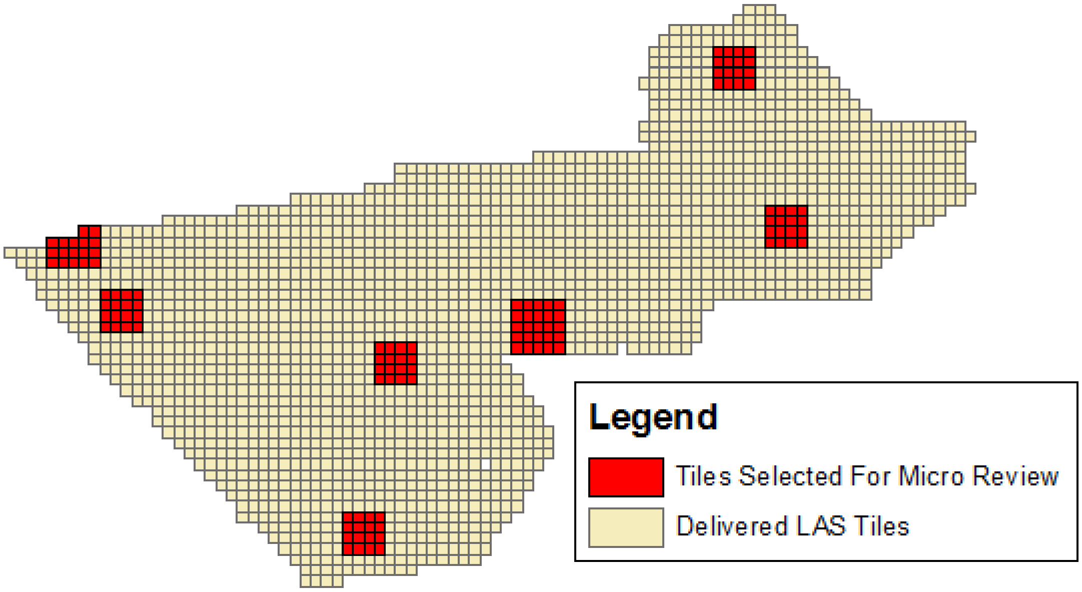

Figure 3 - Tiles selected for the micro review

Aggressive Misclassification

One of the limitations of LiDAR processing algorithms is the ability to differentiate between ground points and vegetation along the edge of a hill or ridge. Since the ground classification algorithm relies on point-to-point distance and angle to determine if a point is ground or non-ground, ground points at the apex of a hill or ridge can be "aggressively" classified out of the ground. Figure 4 below shows ground points in tile C18593 that have been aggressively classified.

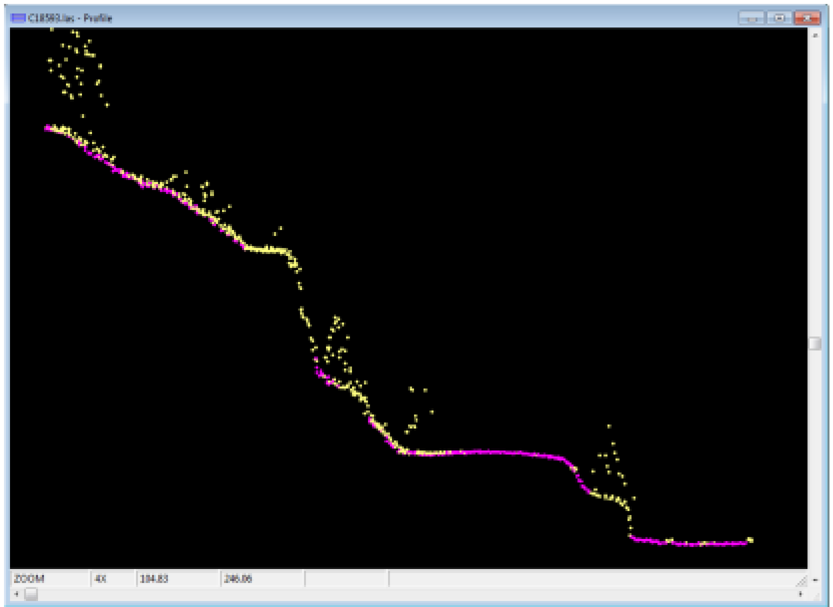

Figure 4 - Aggressive Classification in tile C18593. The purple points are ground and yellow are non-ground.

Artifacts

Artifacts are vegetation, buildings, or bridges that are improperly classified as ground points. Most of the non-ground features are classified by the automated ground algorithms in the LiDAR processing software, but it is necessary to manually review the data and remove any remaining non-ground points from the ground surface. Normally a tolerance of 5% of the vegetation artifacts is allowed as manual classification is sometimes subjective and different analysts will interpret the surface differently. Also, bridges with a distinct deck above the ground are normally removed to allow hydro to flow through during flood modeling. Culverts are not normally removed and will be discussed later in this document.

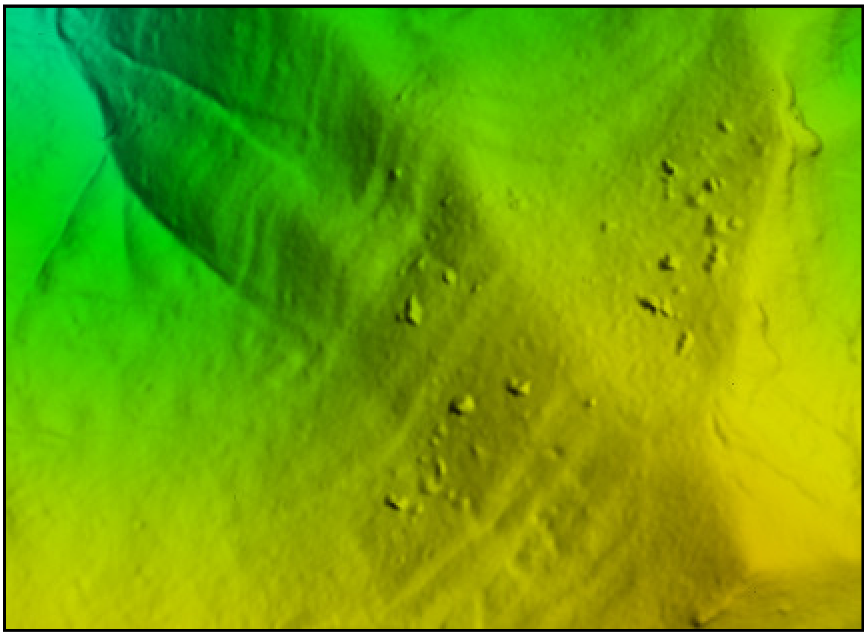

Figure 5 - Tile C20264 showing vegetation artifacts along the side of the hill

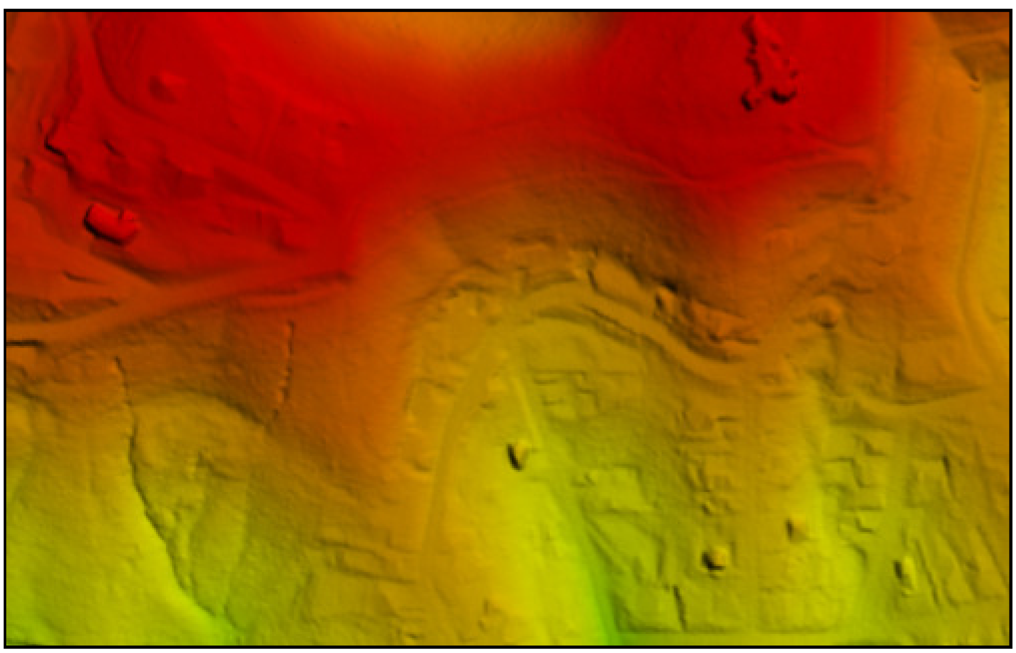

Figure 6 - Tile C18425 showing several building artifacts left in the ground model.

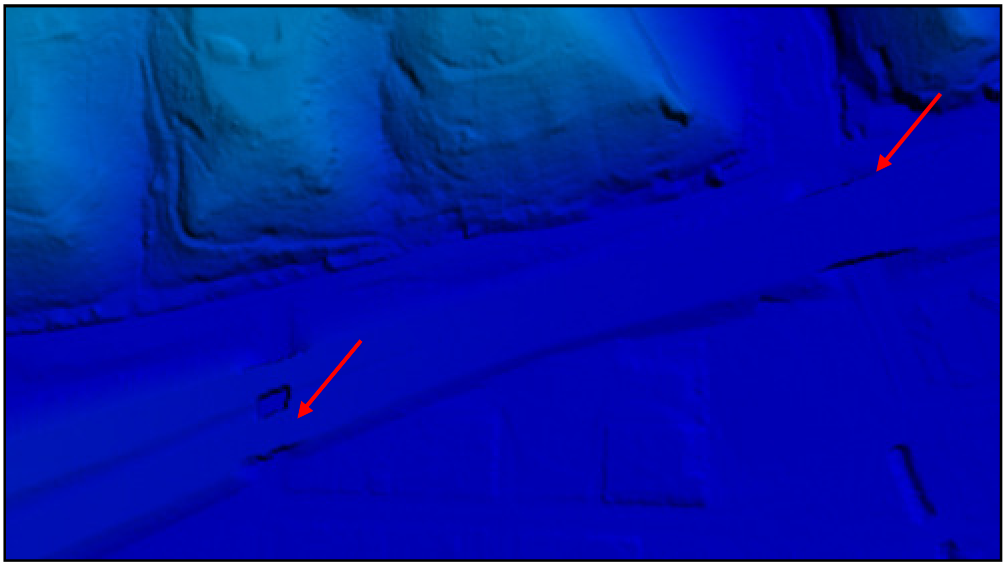

Figure 7 - Tile C18425 showing three bridge artifacts.

Divots

Divots are points that fall far below the expected ground surface. They can occur because of a timing error in the LiDAR sensor or near buildings where the LiDAR pulse is distorted by glass. Because the LiDAR processing software looks for the lowest point near the previously classified ground, the divots are marked as ground and the true ground is treated as non-ground.

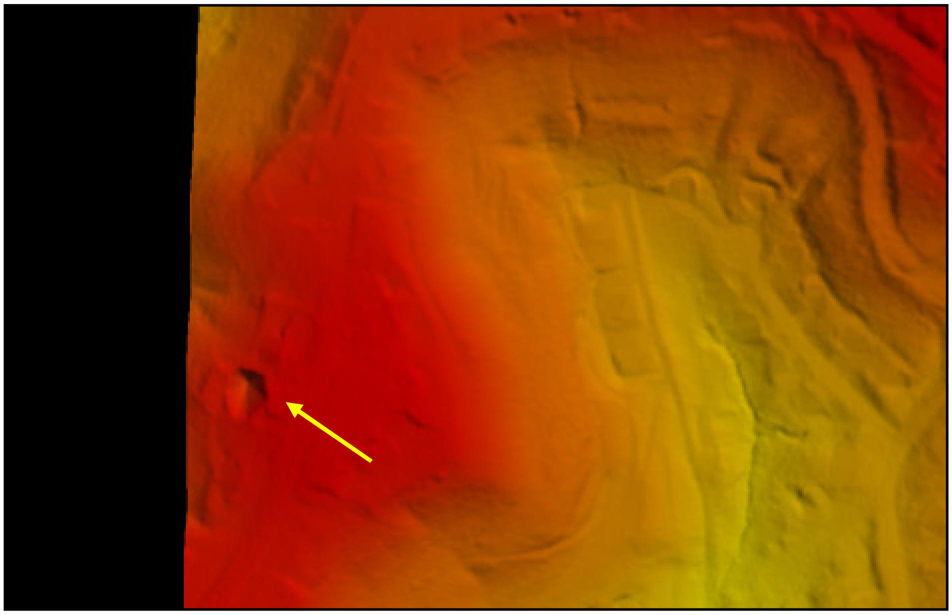

Figure 8 - Tile C18592 showing a divot that causes misclassification of the ground surface

Culvert Misclassification

A culvert is a feature that allows hydro to flow underneath a road, but unlike a bridge, does not have a man-made deck above the ground surface. A culvert can be differentiated from a bridge because it has visible ground between the road and the hydro surface. As mentioned above in the Artifacts section, culverts should be left in the ground.

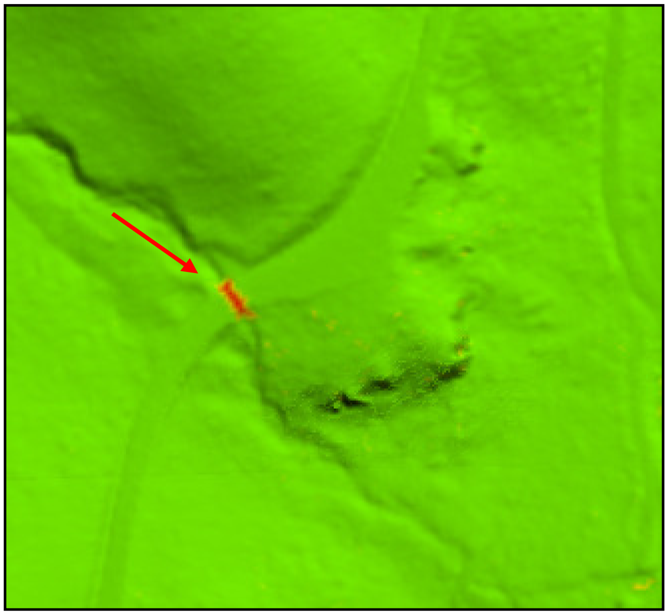

Figure 9 - Tile C18492 showing ground points removed from a culvert

Tile Overlap Effects

Overlap in tiles resulted in inconsistent editing along the tile edges. Many tiles contained vegetation and structure artifacts in these overlapping areas. Figure 10 shows a line of artifacts that were left along the western edge in the ground density model of tile C20585.

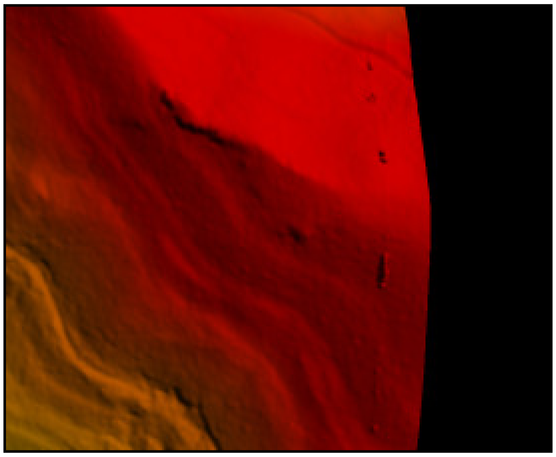

Figure 10 - Vegetation artifacts along the edge of a tile.

In a few cases, a ridge appeared in the overlapping areas. This signifies a change in ground elevation from one tile to the next and is likely a result of flight line offsets. Figure 11 shows a ridge in the overlapping area between tiles C20427 and C20266.

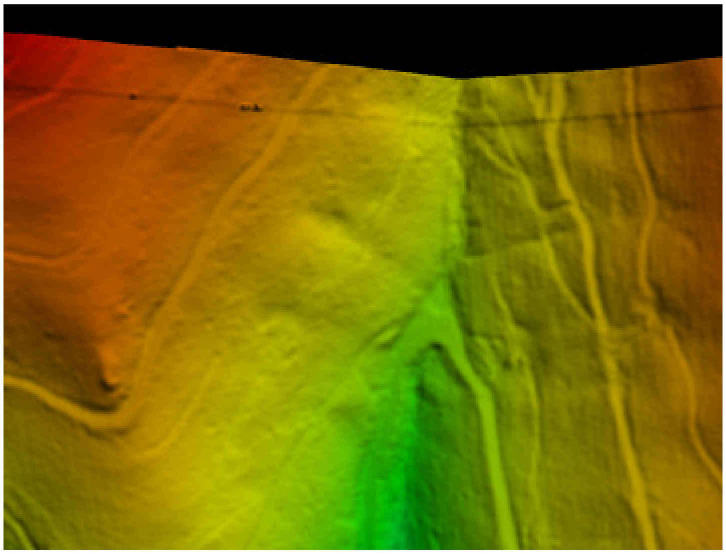

Figure 11 - A ridge formed in the overlapping area between tiles.

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 Third Delivery of West Virginia LiDAR passes the absolute vertical accuracy testing requirements specified by PM61 and the 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 four geographic blocks and uses horizontal projection NAD83/CORS96 Epoch 2002 and vertical datum NAVD88, geoid09, with vertical units of US Survey feet. The Third Delivery LiDAR delivery intersects 75 of these checkpoints. 69 checkpoints were used in the RMSE calculation. Six checkpoints were removed due to their location, surrounding vegetation, and variable terrain. Four land cover categories were surveyed and used for the Third Delivery vertical accuracy assessment: Open Terrain, Weeds/Crop, Forest, and Urban. RAMPP reviewed all survey data to ensure that the checkpoints are adequately distributed over the Third Delivery 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 12 shows all checkpoints over the FEMA area of interest and the Third Delivery bounds. Figure 13 shows the distribution of checkpoints within the Third Delivery by land cover type.

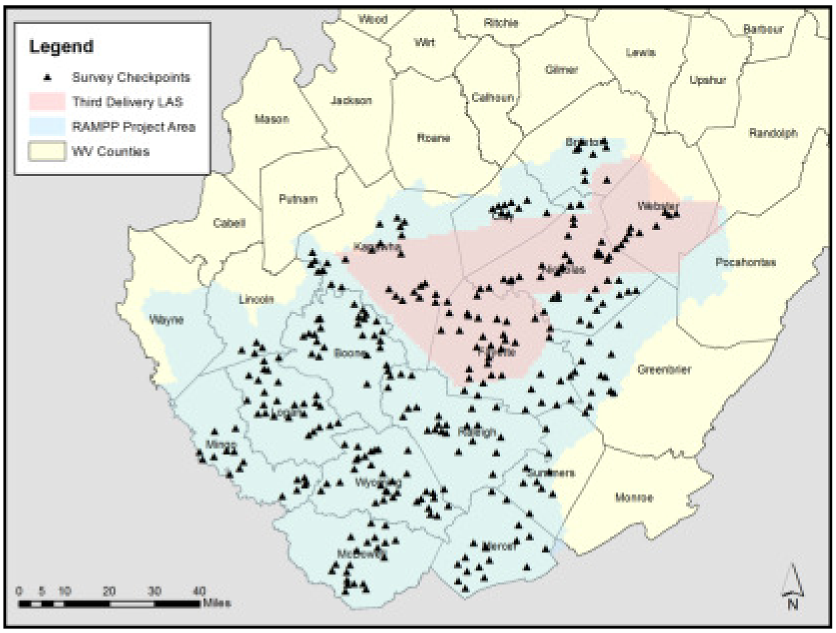

Figure 12 - Survey Checkpoint locations in WV project

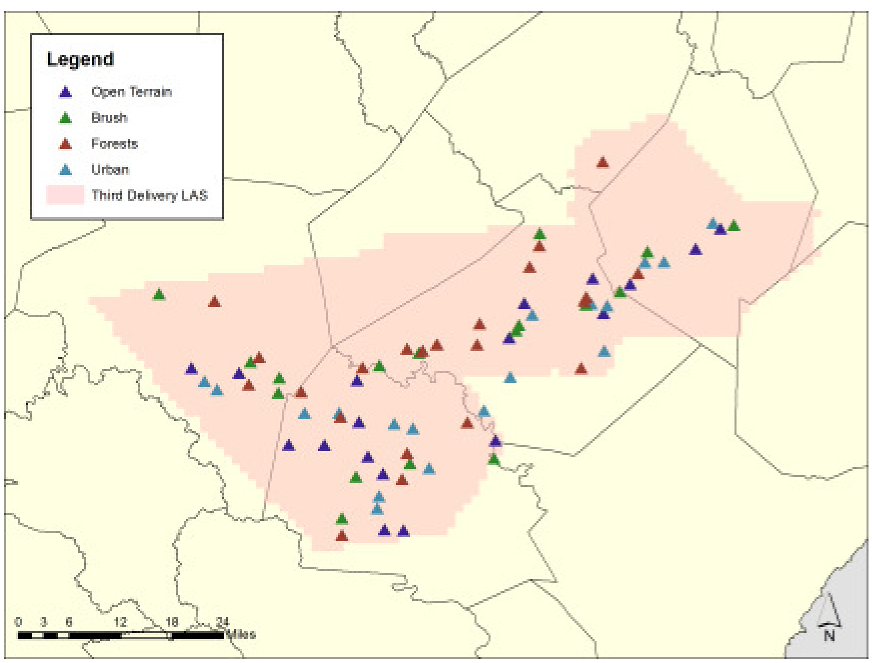

Figure 13 - Checkpoints by land cover type for the Third Delivery LiDAR

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 Third Delivery LiDAR meets the vertical accuracy requirements. Table 2 describes vertical accuracy by land cover type and for the consolidated checkpoints. Table 3 highlights the RMSEZ statistics.

Table 2 – 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=0.363m	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.363 m
Consolidated	69		0.39	
Open Terrain	18	0.28		
Brush	17			0.31
Forest	16			0.52
Urban	10			0.160

Table 3 – Descriptive Statistics for Third Delivery LiDAR vertical accuracy calculations by land cover category.

Land Cover Type	RMSE (m)	Mean (m)	Median (m)	Skew	StdDev (m)	# of Points	Min (m)	Max (m)
Consolidated		0.01	-0.02	1.05	0.18	69.00	-0.29	0.57
Open Terrain	0.14	-0.03	-0.04	1.45	0.15	18.00	-0.25	0.41
Brush		0.04	0.01	0.44	0.15	17.00	-0.19	0.33
Forest		0.11	0.06	0.80	0.23	16.00	-0.17	0.57
Urban		-0.07	-0.10	1.11	0.16	18.00	-0.29	0.36

All of the removed points can be seen in the images below. These points were removed from the RMSE due to their located in heavily vegetated areas. The difference between the checkpoint elevations and the LiDAR elevations for the removed points were all higher than 2.5 meters, which suggests a possible survey issue on those specific points or an error in ground classification.

Figure 14 - Checkpoint WV4_D_07

Figure 15 - Checkpoint WV3_D_37

Figure 16 - Checkpoint WV4_D_39

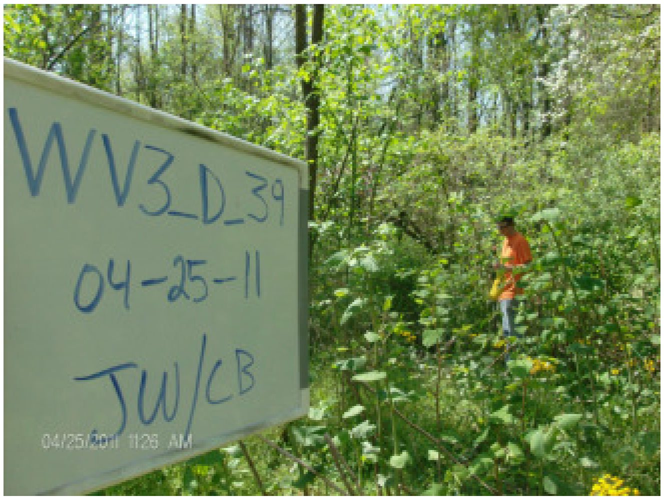

Figure 17 - Checkpoint WV3_D_39

Figure 18 - Checkpoint WV_3_D_25

Conclusions

After a limited quality review of the Third Delivery block of the RAMPP West Virginia task order, RAMPP concludes that the data needs to be corrected in order to meet he the quality and accuracy requirements for FEMA flood plain modeling. The header information for the LAS needs to be updated to include the projection information, and LAS tiles need to be 1500 meters by 1500 meters. There are numerous classification errors in the dataset including divots, culvert misclassifications, and vegetation, building, and bridge artifacts.