To: Alex Nemeth

From: Stephen DiCicco

Date: 4/05/2012

Subject: RAMPP West Virginia LiDAR QA/QC: Tug Watershed 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 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." The delivery includes 1,368 LAS tiles. The dataset is referred to as the Tug Watershed 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.

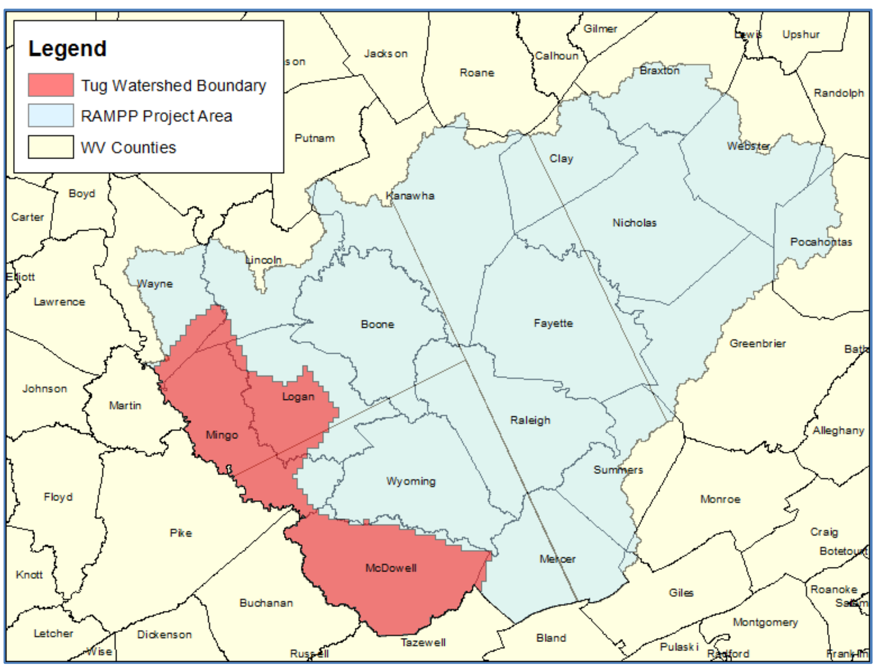

Figure 1 - West Virginia area of interest and Tug Watershed delivery.

The Tug Watershed LiDAR does not meet the accuracy standards required by FEMA for flood plain modeling. There are a number of tiles with a 30 meter elevation offset, which cause the dataset to fail the vertical accuracy test. The data should be sent back to the LiDAR provider for analysis and reprocessing. Additionally there are significant opportunities for quality improvement by the LiDAR provider, including reclassification non-ground artifacts such as vegetation and buildings, recalibration of overlapping flight lines to eliminate ridge/seamlines, and further investigation of a possible geodetic error identified in one tile. These issues are described in detail below.

Completeness & Macro-Level Review

A 100% completeness check was performed on the Tug Watershed 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. Six tiles were missing from the delivery; those tiles are listed below. Four of the tiles are located on the edge of the dataset and may not fall within the project boundary, but this could not be verified because no project boundary file was provided for the review. However, the other two tiles, C028354 and C028476, are located in the middle of the dataset and are within the project boundary.

Missing Tiles Along Edge of Tug Watershed	Missing Tiles in middle of Tug Watershed
C022542	C028354
C028023	C028476
C028308	-
C028435	-

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 Tug Watershed dataset.

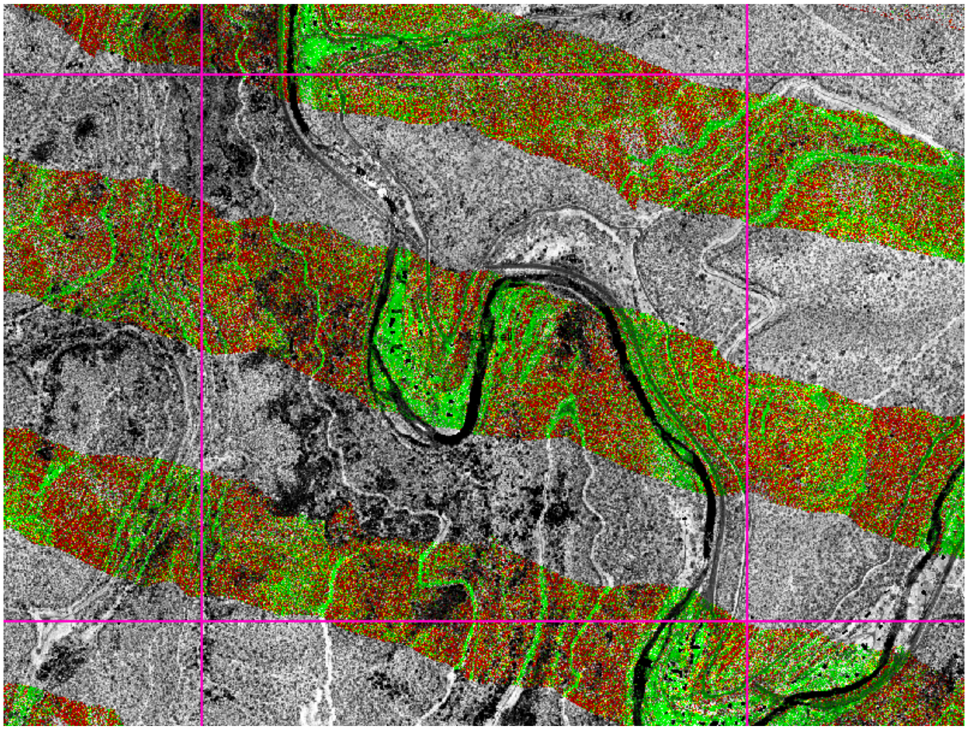

Figure 2 - Delta-Z ortho image of tile C027661

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 reliable. 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 Tug Watershed dataset, where a low delta-Z error is prevalent in the low-relief areas around the river and along the roads.

LAS Header Review

An 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 or Isenburg's LAS Tools.

- 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 88 tiles were selected for the review. Many of these errors are easily fixed, such as vegetation artifacts and aggressive classification. Some of the errors require further review, such as the tile-wide elevation offset.

Figure 3: Tiles selected for the micro review

Aggressive Classification

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 C028413 that have been aggressively classified.

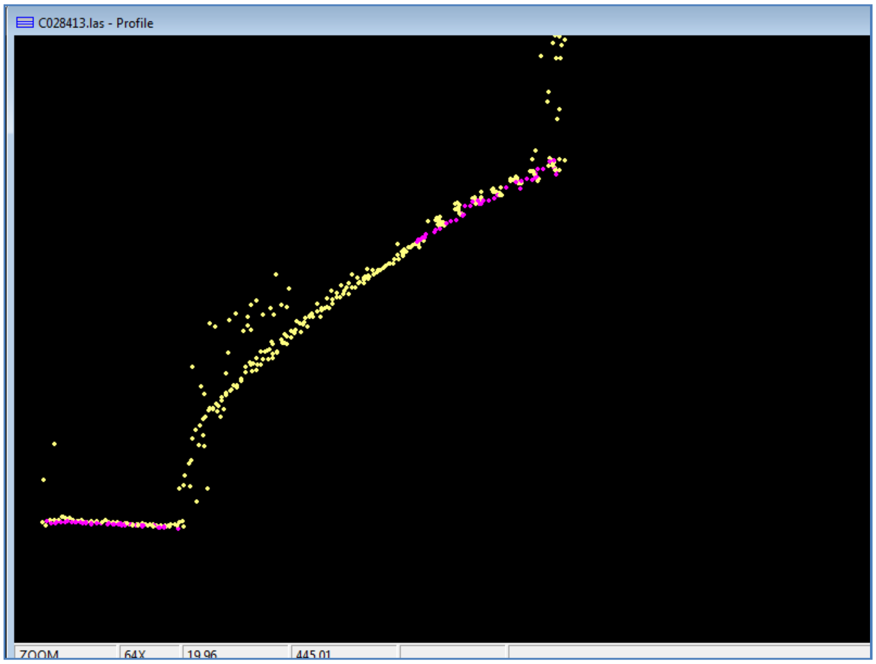

Figure 4: Aggressive Classification in tile C028413. The purple points are ground and yellow are non-ground.

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. The 5% visual review identified over 1300 areas that have vegetation artifacts, over 50 areas with building artifacts, and seven bridge artifacts.

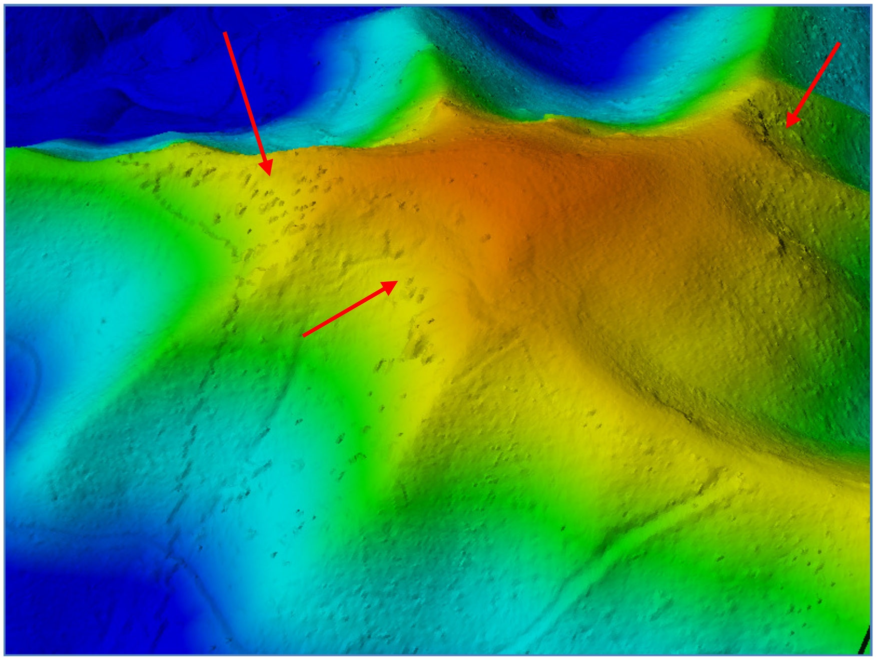

Figure 5: Tile C022986 showing vegetation artifacts along the side of the hill

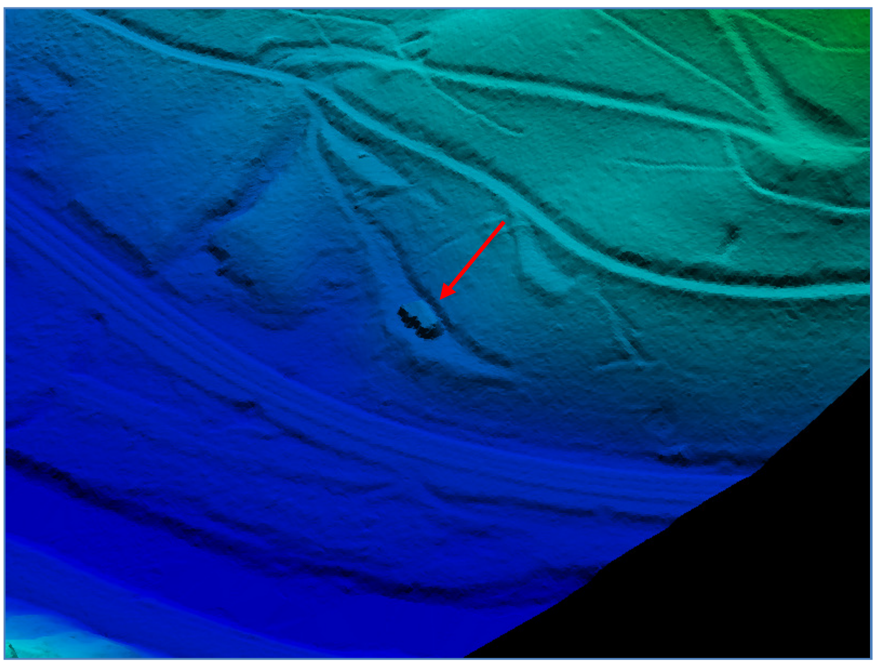

Figure 6: Tile C027654 showing a building artifact

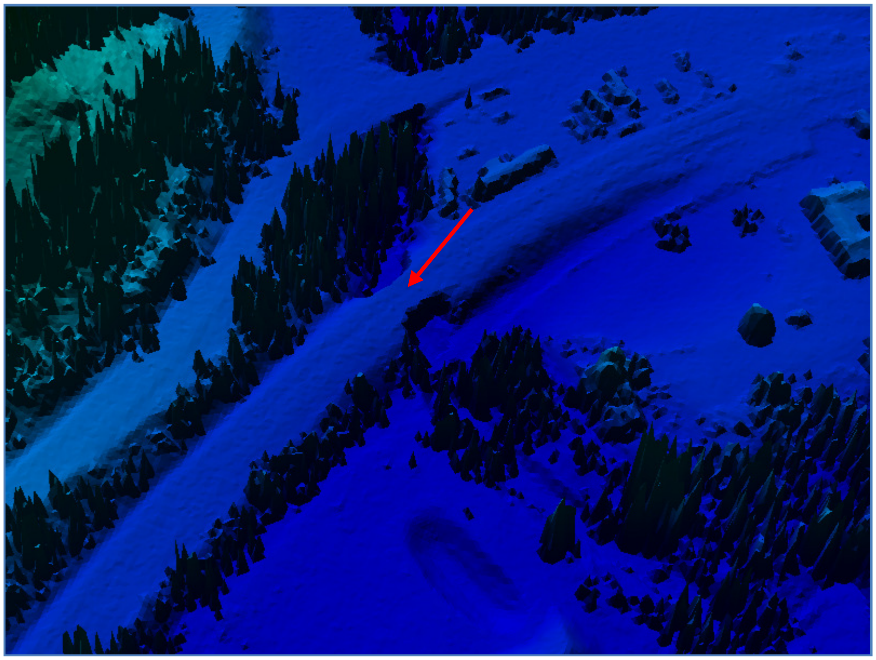

Figure 7: Tile C026594 showing a bridge artifact.

Note that while this image shows the full point cloud, the artifact remains in the ground.

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.

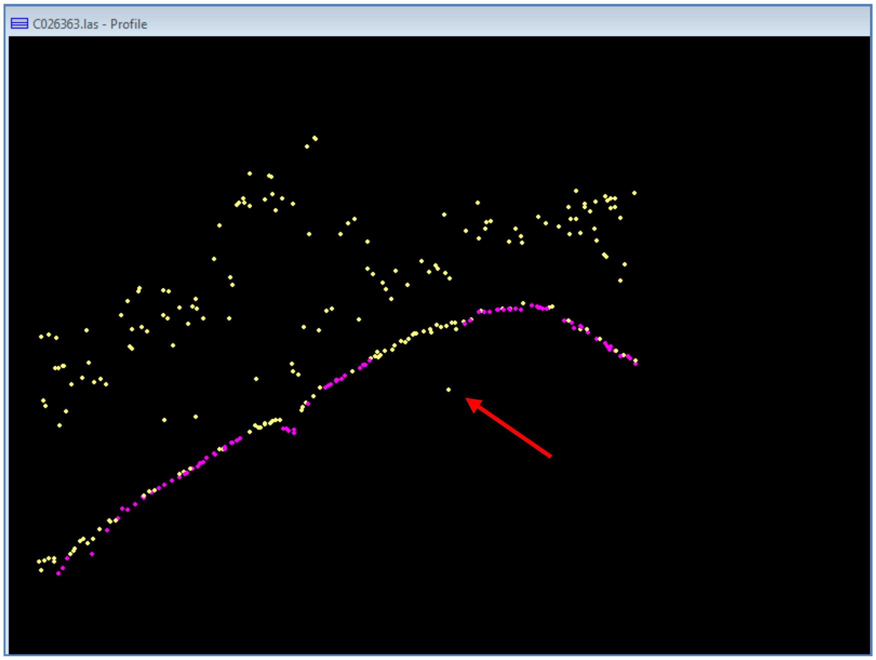

Figure 8: Tile C026363 showing a divot that causes misclassification of the ground surface

Flight Line Ridges

Flight line ridges or seamlines occur when two or more overlapping flight lines are not calibrated correctly. While the review of the Delta-Z ortho images in the completeness check did not find any project-wide calibration errors, several localized issues exist. The data should be recalibrated or reclassified to reduce the ridge to within the accuracy specification set forth in the Statement of Work.

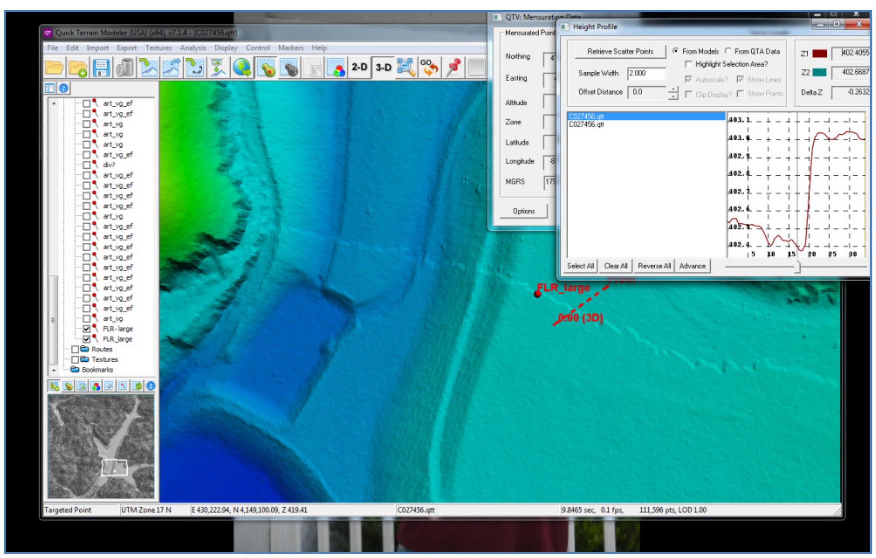

Figure 9: Tile C027456 showing a flight line ridge with an offset of over 0.6 meters

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.

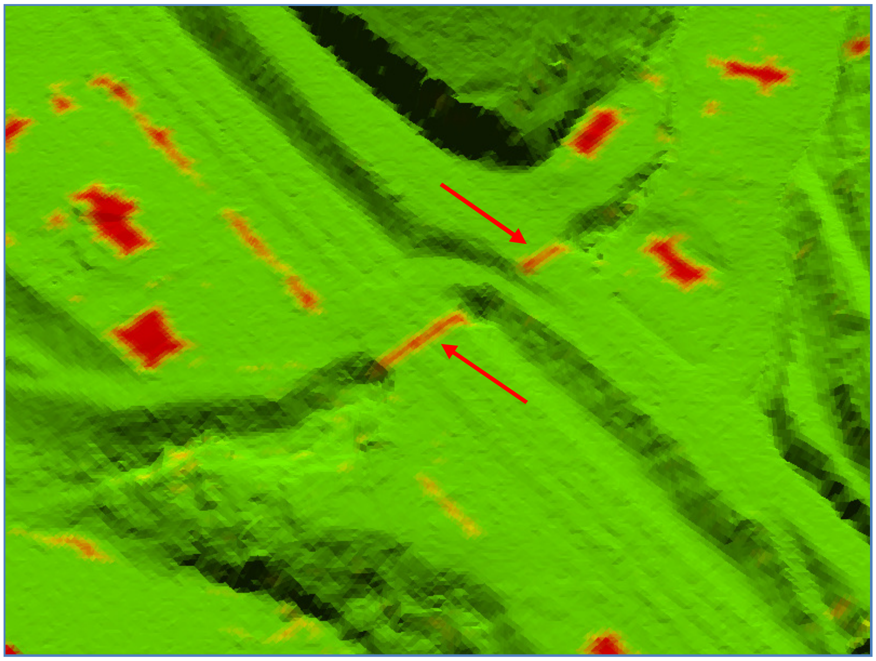

Figure 10: Tile C026478 showing ground points removed from a culvert

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 Tug Watershed delivery of West Virginia LiDAR fails 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 4 geographic blocks and uses horizontal projection NAD83/CORS96 Epoch 2002 and vertical datum

NAVD88, geoid09, with vertical units of US Survey feet. The Tug Watershed LiDAR delivery intersects 41 of these checkpoints. Table 2 lists the four land cover categories surveyed and used for the Tug Watershed vertical accuracy assessment. RAMPP reviewed all survey data to ensure that the checkpoints are adequately distributed over the Tug Watershed 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. shows all checkpoints over the FEMA area of interest and the Tug Watershed delivery bounds. shows the distribution of checkpoints within the Tug Watershed delivery by land cover type.

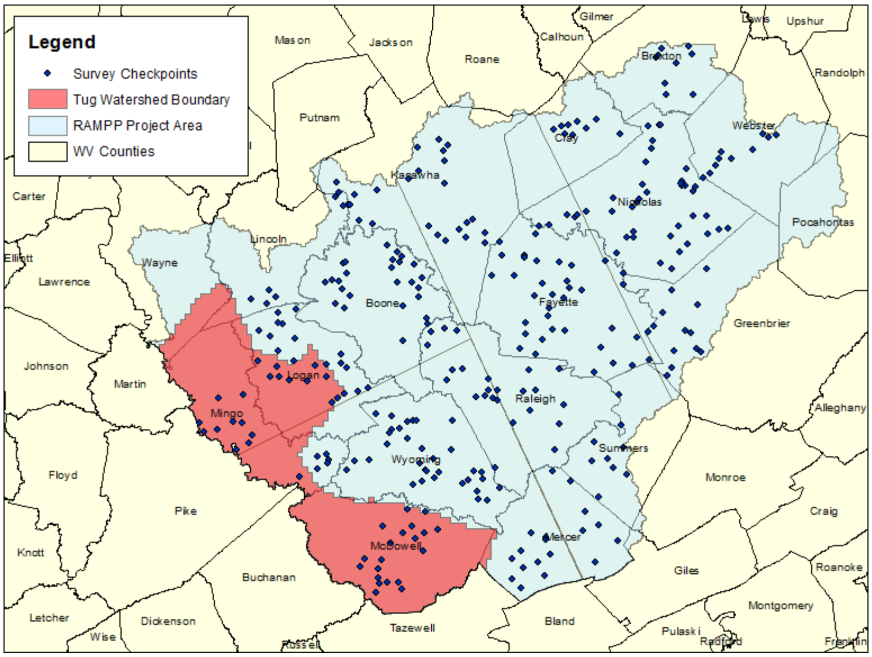

Figure 11: Survey Checkpoint locations in WV project

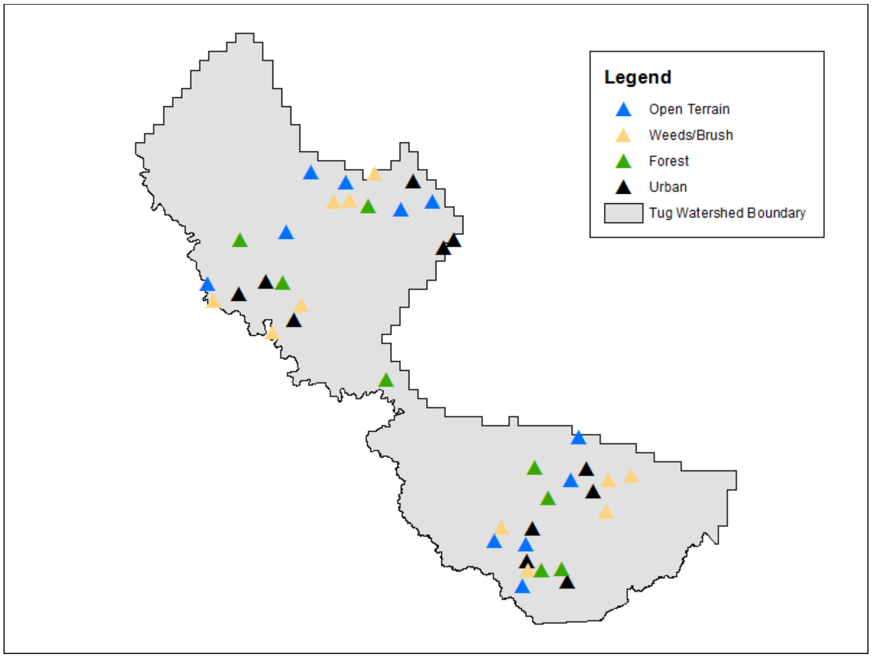

Figure 12: Figure 8- Checkpoint by land cover type for the Tug Watershed LiDAR delivery

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 Tug Watershed LiDAR does not meet the vertical accuracy requirements due to significant elevation error in some of the tiles.

Table **1** describes vertical accuracy by land cover type and for the consolidated checkpoints. Table 2 highlights the $RMSE_Z$ statistics.

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	41		30.898	
Open Terrain	11	0.436		0.398
Brush	11			0.810
Forest	8			31.009
Urban	11			1.164

Table 2- Descriptive Statistics for Tug Watershed 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	10.768	-3.689	0.064	-2.392	10.242	41	-31.014	1.084
Open Terrain	0.223	0.149	0.141	0.966	0.173	11	-0.126	0.554
Brush	0.410	0.268	0.188	1.685	0.325	11	-0.149	1.084
Forest	24.360	-19.225	-30.575	0.644	15.994	8	-31.014	0.237
Urban	0.624	-0.187	-0.123	-2.863	0.624	11	-1.998	0.330

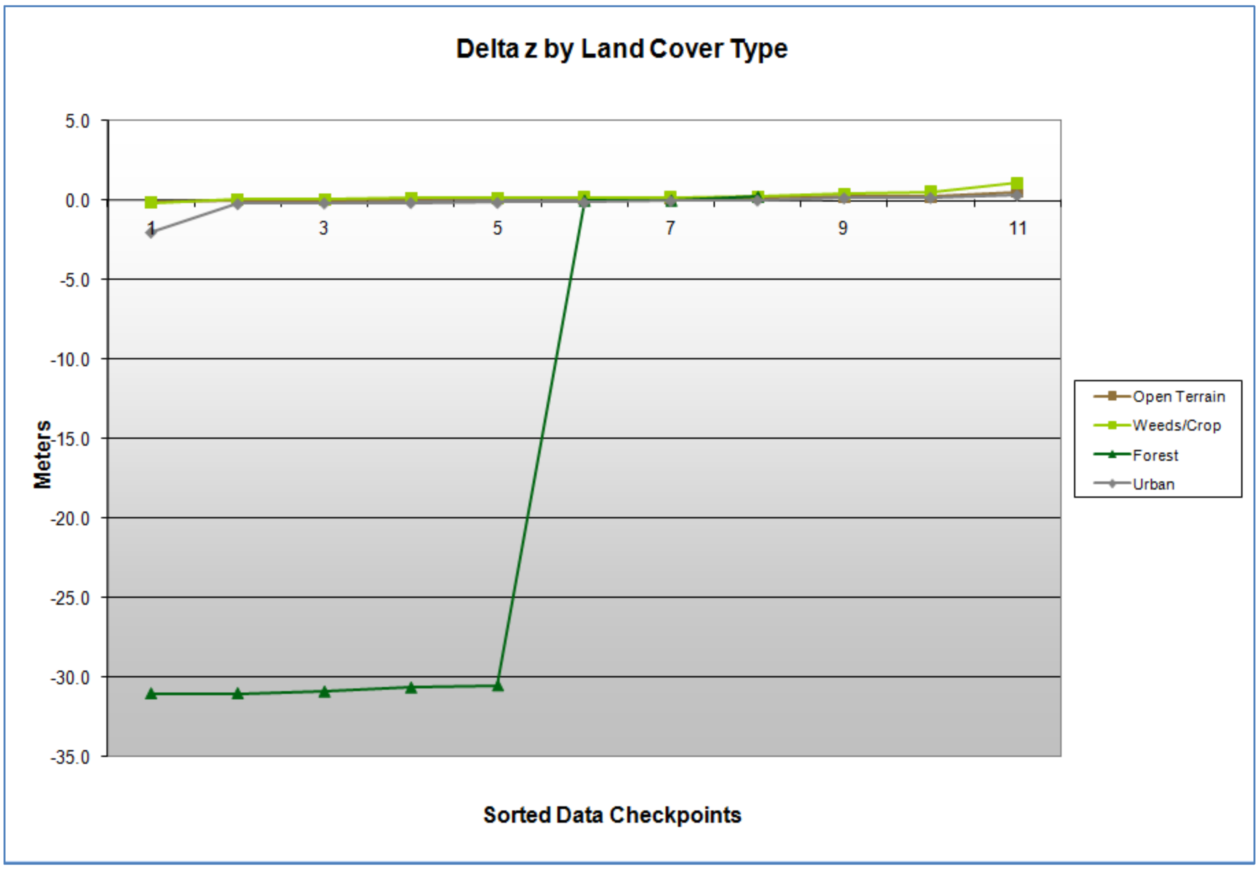

Figure 13: Checkpoint Delta-Z by Land Cover Type

Conclusions

After a limited quality review of the Tug Watershed delivery block of the RAMPP West Virginia task order, RAMPP concludes that the data does not meet the quality and accuracy requirements for FEMA flood plain modeling. There is a vertical alignment error of approximately 30 meters in the McDowell County area and the dataset should be sent back to the LiDAR provider to analyze and correct the issue. Furthermore, there are numerous classification errors in the dataset, including vegetation, building, and bridge artifacts. There are some localized flight line ridge errors that can be addressed by re-calibrating or reclassifying the dataset. Finally, there are some minor classification errors such as divots and culvert misclassifications that can be fixed to improve the dataset, but do not significantly impact the usability of the data for flood plain modeling.

***Note – As of 3/15/2012, the LiDAR provider is aware of the 30 meter offset error in the McDowell County and is correcting the issue.