# An Assessment of LIDAR Data Quality

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Abstract

This paper uses ground survey data as a control to evaluate LIDAR data quality. The comparison is based on coincident points meeting a *maximum horizontal separation criteria*. The initial comparison is further refined to minimize effects of steep slopes. An argument is made for interpolating regular grids from LIDAR point data through the use of TINs, and the resulting grid is compared to the ground survey data. Finally several quality issues relating to processing LIDAR into digital elevation products for hydrological modeling is discussed

## Source Data

In 2001, The WVDEP contracted for the collection of two independent elevation data sets to support an analysis of flooding in three Southern West Virginia watersheds (figure 1). The first dataset was collected by professional surveyors, and consists of a series of transects running perpendicular to stream channels (Figures 2 & 3). A LIDAR dataset was collected by Earth Data International for the same area, and was characterized by a nominal 3-meter spacing interval and an error target of 0.25m. The LIDAR flight was conducted in December of 2001 during leaf-off conditions. A bare earth model, processed by Earth Data, was used for this study.

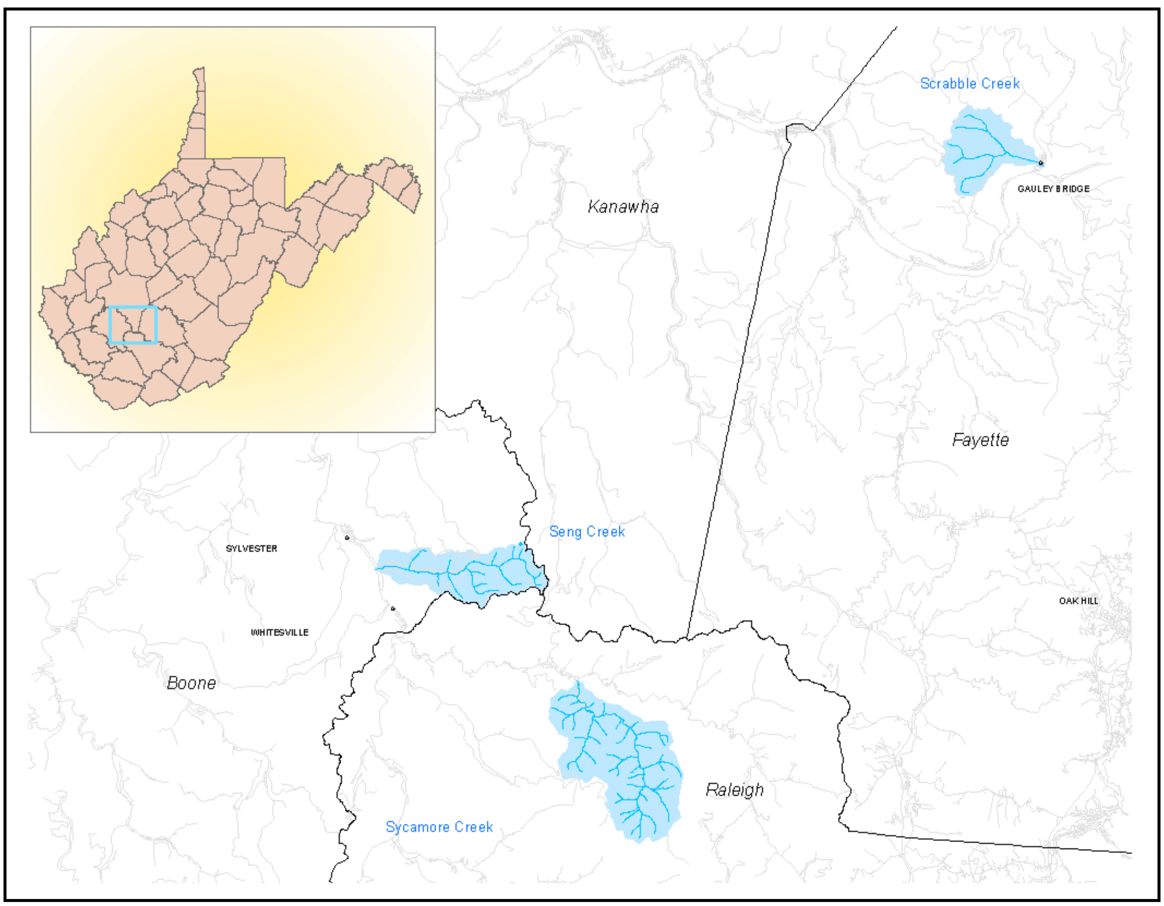


Figure 1. Location of Watersheds used for LIDAR & survey data comparison.

Figure 2. Field survey data collection.

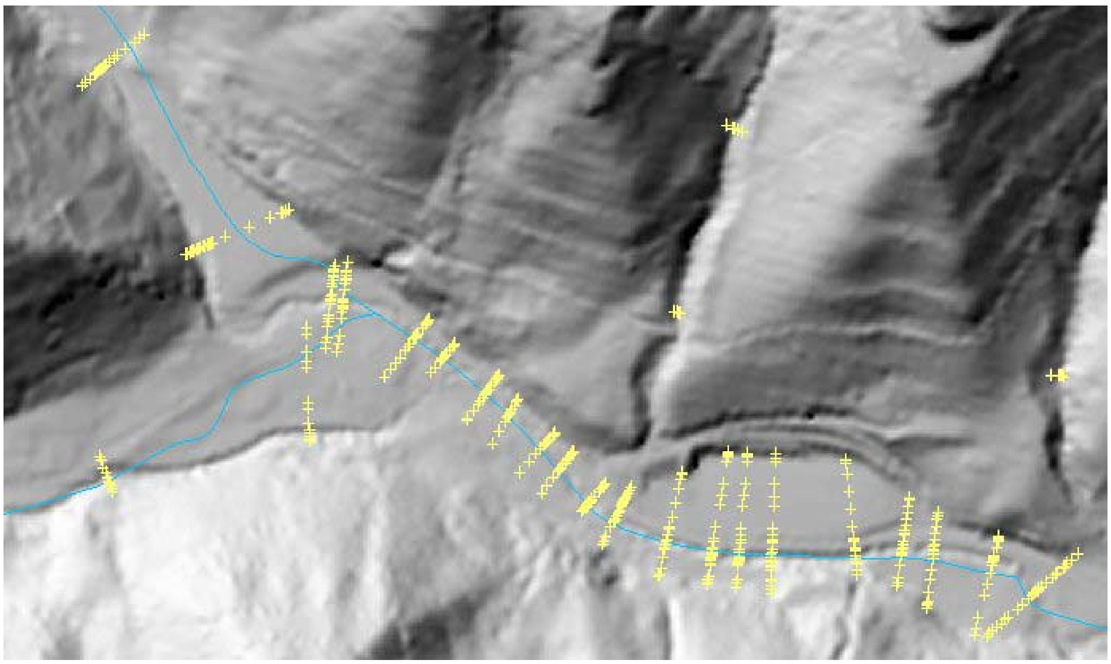
Figure 3. Field survey transects for a portion of Scrabble Creek Watershed, with LIDAR-derived hillshade as backdrop.

## Evaluating LIDAR Point Data

Comparison between LIDAR spot elevations and survey transects was conducted by selecting LIDAR points falling less than 1 meter from a coincident survey point (Figure 4). This resulted in 414 test points for the comparison. The results are shown in table 1, where mean, median, min, and max values were calculated from absolute elevation differences, in meters, between LIDAR and survey points.

| Watershed | Samples | RMSE | Mean Absolute Difference | Median Absolute Difference | < 0.25m |
|---|---|---|---|---|---|
| Scrabble | 193 | 0.71m | 0.32m | 0.32m | 74% |
| Seng | 154 | 0.65m | 0.36m | 0.18m | 62% |
| Sycamore | 67 | 0.53m | 0.26m | 0.14m | 67% |
| Total | 414 | 0.66m | 0.33m | 0.14m | 68% |

Table 1. Absolute elevation differences for coincident LIDAR and survey test points having <1m horizontal separation

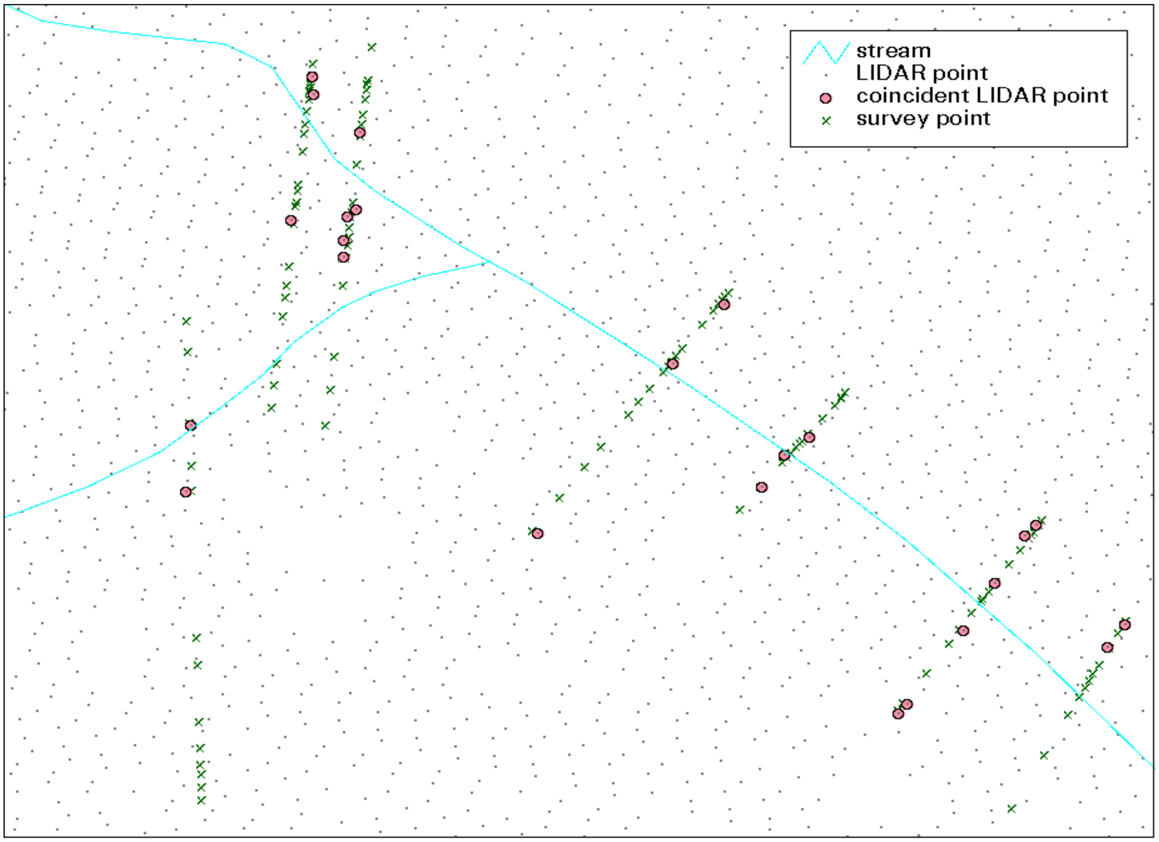

Figure 4. Coincident LIDAR points selected for evaluation based on proximity to survey points, section of Scrabble Creek.

Limitations of this comparison relate to the fact that survey points are concentrated in stream channels, and do not represent a statistically valid sample. It is not possible, therefore to make statistically valid claims about the nature of the entire LIDAR dataset based on this sample. On the other hand, it is arguable that topographical conditions outside the surveyed area are no more challenging, and therefore no more prone to error, than the surveyed areas. Generally, it could be expected that rounded hillsides wouldn't be any more problematic than stream channels, with the possible exception of man-made or naturally occurring cliff faces.

One condition that may have biased the initial comparison involves steep slopes. For example, a horizontal separation of 1 meter between LIDAR and survey points on a 45 degree slope could produce a real vertical difference of 1 meter, even if both measurements were perfectly accurate. Figure 6 depicts absolute elevation differences in coincident points ordered by slope for Scrabble Creek. The relationship between slope and error for Scrabble Creek is characterized by a positive correlation of 0.39, reflecting the fact that the worst errors are associated with outliers occurring in steep slope areas. The cumulative mean absolute difference line shown in Figure 6 reinforces the idea that steep slope conditions produce outliers that adversely affect results. For example, if coincident test pairs are limited to points occurring on slopes less than 15 degrees, the outcome is substantially improved (table 2).

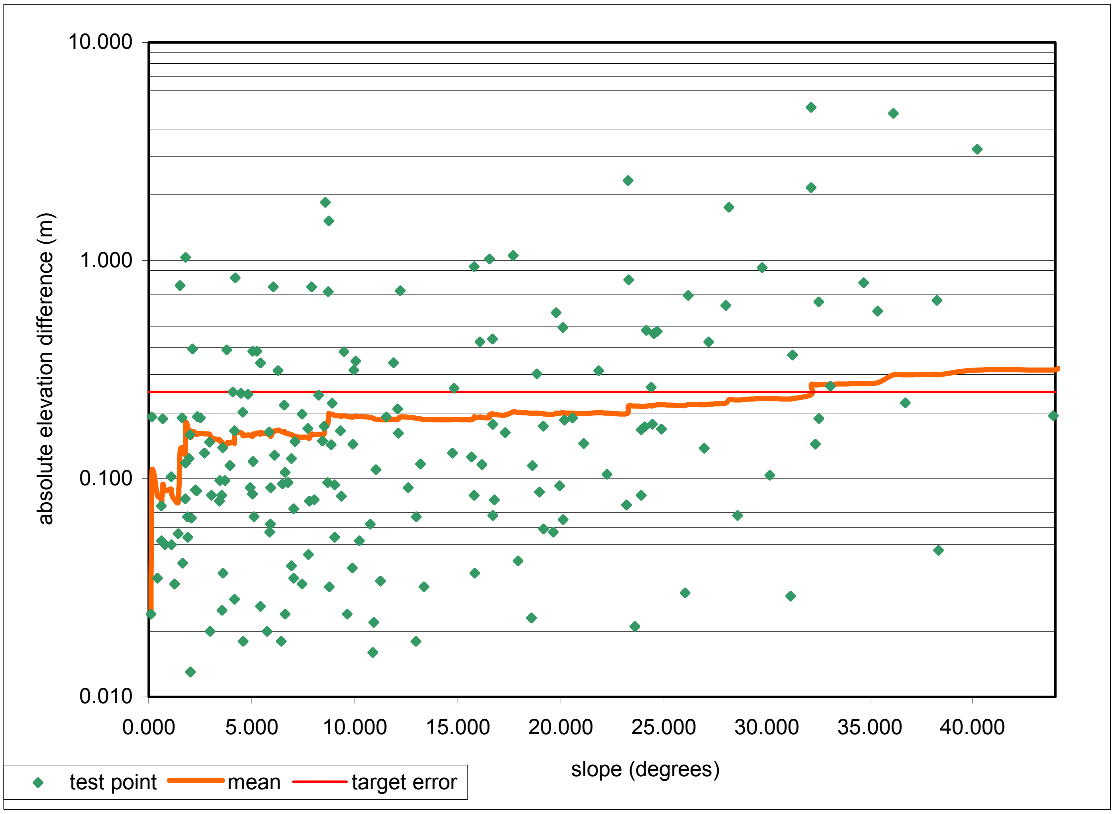


Figure 6. Relationship between slope and absolute elevation difference for coincident points in Scrabble Creek watershed.

| Watershed | Samples | RMSE | Mean Absolute Difference | Median Absolute Difference | < 0.25m |
|---|---|---|---|---|---|
| Scrabble | 122 | 0.33m | 0.19m | 0.10m | 80% |
| Seng | 98 | 0.54m | 0.30m | 0.17m | 69% |
| Sycamore | 49 | 0.29m | 0.19m | 0.13m | 78% |
| Total | 269 | 0.41m | 0.23m | 0.13m | 76% |

Table 2. Absolute elevation differences, LIDAR vs. Survey, for points falling on slopes <15 degrees.

While omitting steep-slope cases from the comparison improves the apparent agreement between the two datasets, it should be noted that steep slopes can produce real error, for example, because of small inaccuracies in calculating the horizontal coordinates of the point. It is reasonable to believe that hillsides that slope away from the sensor would cause relatively larger errors because of the acute intercept angle between the slope of the ground and the signal path fro the sensor. It is likely, therefore, that the low slope analysis removed some real error along with artifacts of the analysis procedure. However, overall errors were remarkably low in both cases (with and without steep-slope points), considering there were many opportunities for LIDAR returns from obstacles near survey points, such as bridges, culverts, rocks, vegetation, and the sides of narrow washouts. 148 of the sample points indicated an elevation difference of 10cm or less, which is remarkable for two datasets collected independently using completely different technologies. LIDAR results may have been aided by a leaf-off condition that allowed more effective canopy penetration, as well as effective post processing of a multiple-return data set.

## Interpolating LIDAR to a Regular Grid

Interpolation to a regular grid from LIDAR point data takes place in a data rich environment, so that most point interpolation algorithms offer limited potential advantage, while adding considerable processing time. In some cases, these algorithms can produce undesirable results. For example, IDW can produce a *corduroy* or ripple effect, while spline algorithms can produce anomalies at features such as cliff faces. The method used for this analysis was to create a TIN model from the LIDAR point data, then to linearly interpolate a grid (or more precisely a lattice) from the TIN structure, with a cell size approximating the nominal point spacing in the initial LIDAR data. This method offers the advantage of being conceptually simple and very fast—about 5 minutes vs. over 9 hours for a spline interpolation. The mean difference between the tin-grid and spline grids was 0.16m, indicating very close agreement across most of the datasets. Larger deviations occurred along terrain breakpoints such as ridges and hollow bottoms, and along contour mining highwalls. As the spline algorithm attempted to fit a continuous curvature to abrupt landscape changes, it would produce oscillations that deviated from the linear interpolation of the tin-lattice.

TIN creation algorithms can incorporate breakline data, which facilitate proper representation of features such as waterbodies and retaining walls. Figure 7 depicts the utility of using breaklines to model sediment control ponds. Because the LIDAR dataset contains data gaps where water occurs, a linear interpolation is performed from points along the shorelines, which leads to an inaccurate representation of the water surface in the image on the left. Selecting appropriate elevations to be coded with the breakline polygons is not a certain process, though some guidance can be obtained by sampling LIDAR elevations near outlet points of the pond or lake. Topographic maps may have pool elevations for larger features.

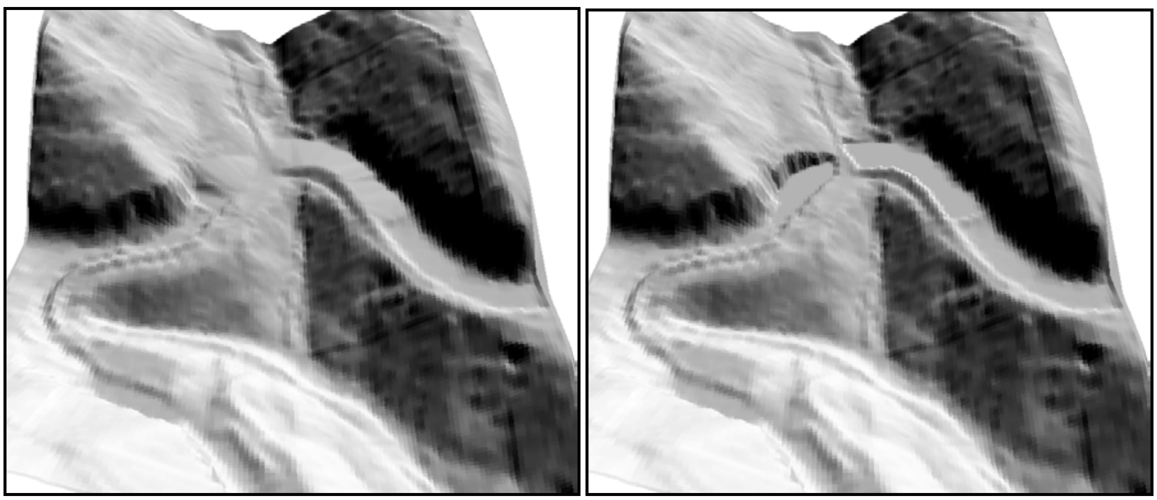

Figure 7. Errors produced by gaps in LIDAR data for waterbodies (left) can be corrected using breakline polygons (right) during the TIN creation process.

It can be expected that some precision would be lost when deriving a regular grid, and this is borne out in table 3. Table 3 depicts the results of comparing coincident points between the grid and survey data. An overall 20cm decrease in mean absolute difference is observed, though nearly half (46%) of the coincident points still meet the error criteria for the original dataset.

| Watershed | Samples | RMSE | Mean Absolute Difference | Median Absolute Difference | < 0.25m |
|---|---|---|---|---|---|
| Scrabble | 478 | 0.84m | 0.48m | 0.23m | 53% |
| Seng | 642 | 0.94m | 0.61m | 0.38m | 39% |
| Sycamore | 187 | 0.59m | 0.35m | 0.20m | 56% |
| Total | 1307 | 0.86m | 0.53m | 0.28m | 46% |

Table 2. Absolute elevation differences, LIDAR vs. interpolated grid.

## Modeling Drainage Channels

Embedding vector stream channels into USGS 30-meter elevation data is a necessary operation for creating and effective DEM for use in hydrological modeling. However since even 1:24,000 scale streams are less detailed than what LIDAR can potentially produce (Figure 8), the embedding of vector stream data should be avoided if possible. For mountain areas, drainage channel delineation can be relatively successful after simply performing a sink fill operation. Figure 8 depicts all channels with drainage areas larger than 4 acres. The channels were vectorized from a reclassified flow accumulation grid. Drainage channel delineation may be less successful in flat areas unless a significant embankment exists which is higher than the error present in the grid. Lakes, in-stream ponds, and wide rivers would require special processing, *e.g*. artificial embedding of channels, before producing an effective stream layer.

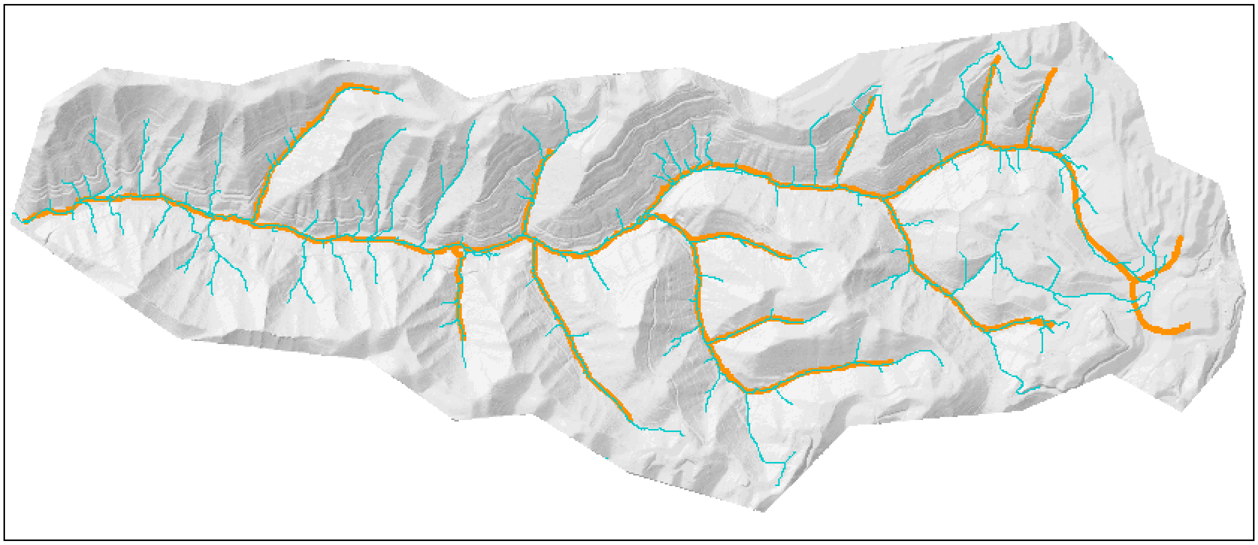

Figure 8. 4-acre drainage channels extracted from the LIDAR-derived grid, compared with 1:24,000 streams in yellow.

Even in relatively steep slope areas, unexpected features can cause undesirable results. Figure 9 depicts an abandoned railroad grade over a culvert. A sink fill operation produces a false 'lake' which leads to errors in delineating the stream channel (left image). In this case it was necessary to embed a short drainage segment in the grid to effectively cut through the fill prior to performing drainage channel extraction (right image). A breakline also could have been used during the TIN creation process to correct for this feature.

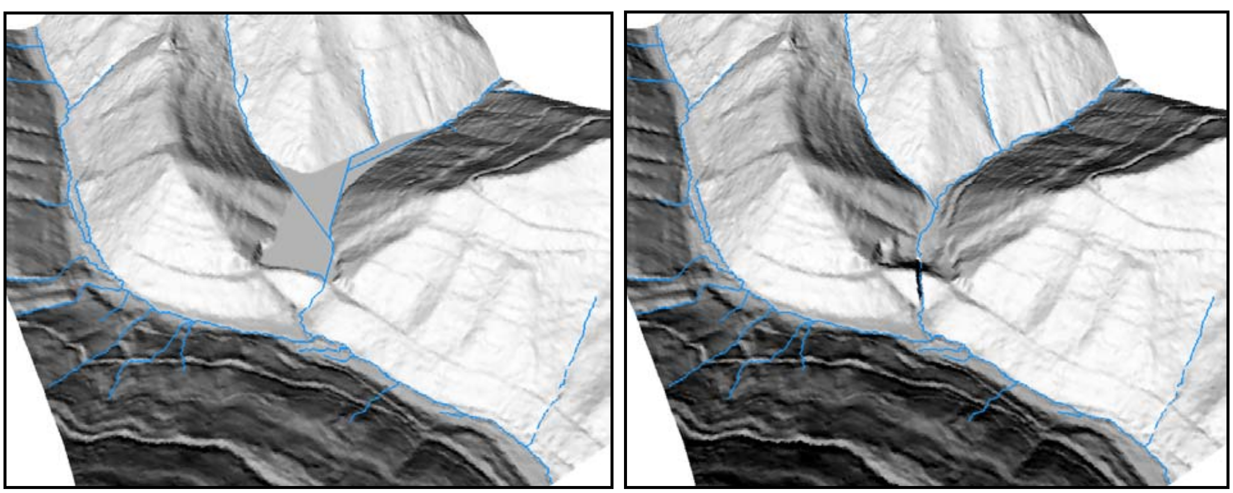

Figure 9. An abandoned railway line produced a false 'lake' during processing to extract drainage features (right). The fill had to be breached in order to accurately depict drainage above the apparent obstruction (left).

Finally, comparing 1:24,000 DLG stream data with LIDAR-extracted drainage features brings up the question of consistency of stream layers derived from paper vs. elevation models. It is not just a question of the higher level of detail possible for drainage layers extracted from LIDAR. Highly accurate elevation data can produce vector drainage layers that depict a *consistent* level of detail that holds across the entire dataset. This consistency is based on the criteria of the minimal drainage area used as a cutoff value when creating the drainage layer. This concept is readily understandable by potential users of the data, and does not rely on thousands of judgments made by numerous cartographers regarding what is, or is not, a stream, and whether it should be depicted at a particular map scale.