DEVELOPMENT OF A 1/9TH ARCSECOND ELEVATION DATASET FOR WEST VIRGINIA

Kevin Kuhn, Analyst
Evan Fedorko, Analyst
West Virginia GIS Technical Center
West Virginia University
Morgantown, WV 26501
kevin.kuhn@mail.wvu.edu

ABSTRACT

“The digital elevation model is the most useful representation of terrain in a GIS.” (Longley et al., 2001)

West Virginia is the first state in the nation to complete statewide coverage of 1/9 arc-second (3-meter) resolution digital elevation models as part of the USGS National Elevation Dataset (NED). West Virginia has recently come into a wealth of spatial data as part of the efforts of the State Addressing and Mapping Board (SAMB). A major element of this data collection was statewide 1:4,800 color photography. Using stereo pair photogrammetric methods, elevation points and breaklines were collected from this photography. This paper will discuss the process we utilized to convert elevation points and breaklines into USGS DEMs. We will also consider the integration of the data into the NED at the 1/9th arcsecond level.

INTRODUCTION

Across the GIS user community, there exists a growing need for a single, accurate and consistent source of base mapping information. For many years this source has been the USGS. With recent advancements in technology and techniques, traditional paper maps are being replaced with web-based applications and disseminated mapping programs. The USGS has recognized that their role as a cartographic map producer is diminishing and that with the advancement of GIS and Web-mapping services, digital cartography may replace historical cartographic traditions. Consequently, USGS’s is shifting from its traditional role as a map producer to an overseer of the mapping (GIS) community. This will provide leadership and organization for the new distributed mapping base and help continue the use of Federal data standards, and inter-state data integration and sharing. Thus, USGS has implemented new strategies, including an online application called The National Map. The National Map’s goal is to provide seamless, current, high resolution spatial data for the entire US through partnerships with federal, state and local data stewards. It is through this website that any user can access a multitude of datasets offered at the national, state and local level. It is through this website that the NED is distributed.

Digital Elevation Models (DEM) and Digital Terrain Models (DTM) are widely used today in many remote sensing and GIS studies. Generally speaking, a DEM is a digital representation of the bare-earth. A DEM is generally available as a raster, grid, triangular irregular network (TIN), or one of many less common data types. A DTM is similar, but often includes more irregularly spaced sample points along with geological surface features (such as ridges and peaks, which are commonly represented as breaklines) that more accurately depict the bare-earth terrain. DEM and DTMs’ can be used directly for associating elevation with overlying data, or they can produce derivative information such as slope and aspect. DEM and DTMs’ are constructed through various methods such as; using existing contour data (such as a USGS 7.5 minute quad), stereoscopic terrain extraction, Lidar and IFSAR data and other remote sensing techniques. In the late part of 2004, the West Virginia GIS Technical Center (WVGISTC) began determining the best course of action to deliver new, accurate elevation data to the geospatial community of West Virginia.

Project History

In 2001, passage of WV State Senate Bill 460 created the Statewide Addressing and Mapping Board (SAMB). SAMB was charged with, among other things, assigning city style addresses to every structure in the state as part of an effort to expedite emergency response. With a predicted 400,000+ structures needing re-addressing, there was a
definitive need for implementation of a Geographic Information System. In order to accomplish such a large task, the SAMB board of directors hired contractors Michael Baker Jr. Inc., microDATA GIS, Inc. and BAE Systems ADR, Inc. BAE collected aerial photography in the spring of 2003 to support the SAMB data needs.

The WV Department of Transportation (WVDOT) had previously contracted engineering studies for projects that required cut and fill calculations. Because BAE was only producing DEMs for orthophoto production, the DEM’s would not be suitable for WVDOT uses. WVDOT contributed additional funding to the project, so that additional ground points and breaklines would be collected during the DTM generation phase to enhance the resolution of the dataset. This would enable WVDOT to perform cut and fill calculations in-house with new, high resolution elevation data.

Recognizing the opportunity, the WV GIS Technical Center (WVGISTC), SAMB and the U.S. Geologic Survey partnered to integrate the high resolution elevation data from the addressing and mapping project into The National Map.

DATA

In March through early May of 2003, natural color aerial photography was flown for the entire state of West Virginia, an area covering roughly 25,000 sq miles. The imagery was flown at 1:4,800’ scale (two foot pixels) to provide a collection base for structures and planimetric features, such as roads. Over ten aircraft through five sub-contractors were used to accomplish this task in the allotted time.

Film negatives were developed and then scanned to digital files at 2032 pixels per inch, equal to 2 feet per pixel. These scans were then transferred to BAE’s softcopy photogrammetric workstations. The softcopy aerotriangulation process used to correct and register the images minimized the need for ground control points, saving money and time.

Once registered, the imagery was used to extract the elevation through BAE’s softcopy workstations semi-automatically and through manual collection, forming mass point and breakline datasets. The aerial photography was also used to collect streams and water bodies. These hydrological features were also used to create the TIN.

The imagery and all subsequent data was produced in a grid system set up for the statewide addressing and mapping project. The grid system was comprised of 10,000’ X 10,000’ blocks (10k tiles) nested in groups of 5 (50k tiles). The data was projected in State Plane North (feet) or State Plane South (feet) projection, North American Datum 1983, North American Vertical Datum 1988.

Preliminary Accuracy Assessment

As a check of SAMB elevation point and breakline data quality, we compared the raw elevation points to LIDAR DEM surfaces generated in Gilmer County, West Virginia. We based this accuracy assessment on the statistical method for estimating the accuracy of spatial data based on ground positions of higher accuracy as outlined by the National Standards for Spatial Data Accuracy (FGDC, 1998).

The NSSDA provides a statistical methodology to compute a vertical accuracy statistic for a dataset. First, we selected two study areas, both in Gilmer County, West Virginia. In 2004, LIDAR elevation data was collected and processed to produce tiled DEMs. We compared eleven tiles of new elevation points and twelve LIDAR DEM tiles. First, using the ET Geowizards toolset, we converted the POINT ZM type shapefiles to POINT type shapefiles which contained an attribute of the elevation (feet) in the table. We then projected these from West Virginia state plane south to UTM Zone 17 North, to match the LIDAR elevation data. Using a Visual Basic script from ERSI’s technical support website, we added the elevation from the underlying LIDAR DEMs to each point. Next, in order to weed out some of the potential error in the LIDAR data, we used DOQQs to digitize several bare earth or open field areas and took a subset from the elevation points using those polygons.

We utilized Microsoft Excel to complete the statistical analysis. We completed two statistical analyses, one for all data points in our test area, and one for only those data points that intersect bare earth or open fields. First, we calculated the root mean square difference (RMSD) statistic. We use the word “difference” instead “error” because what we are measuring isn’t really error so much as it is a statistical difference measured between two datasets. As we are making the assumption that LIDAR data is essentially more accurate than the SAMB point and breakline data, and not actually citing any conclusive accuracy of the LIDAR data, we feel it is necessary to make this distinction. The RMSD was used to calculate the NSSDA accuracy statistic. The root mean square statistic is calculated via the following equation:
\[ \text{RMSD}_z = \sqrt{\frac{\sum (X_{\text{groundvalue}_i} - X_{\text{testvalue}_i})^2}{n}} \]

Where

- \( X_{\text{groundvalue}_i} \): ground truth point of the \( i \)th point in the dataset
- \( X_{\text{testvalue}_i} \): test point of the \( i \)th point in the dataset
- \( \sum^2 \): sum of the set of squared differences between the ground and test data
- \( n \): total number of test points

The resultant value is then multiplied by 1.96, the NSSDA constant for a 95% confidence accuracy statistic. This number tells us, in map units, the expected plus or minus accuracy of the data (FGCS, 1988). The table below contains the statistics we calculated.

### Table 1. Difference statistics

<table>
<thead>
<tr>
<th>Test Group</th>
<th>( n )</th>
<th>Mean Error (m)</th>
<th>Mean Error (ft)</th>
<th>RMSD (m)</th>
<th>NSSDA (m)</th>
<th>NSSDA (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL</td>
<td>9288</td>
<td>-0.6819</td>
<td>-2.2372</td>
<td>1.7714</td>
<td>3.4720</td>
<td>11.3910</td>
</tr>
<tr>
<td>BARE EARTH</td>
<td>463</td>
<td>-0.5822</td>
<td>-1.9101</td>
<td>1.0669</td>
<td>2.0912</td>
<td>6.8609</td>
</tr>
</tbody>
</table>

Our initial examination of error gave us pause as the returned NSSDA value is over 11 feet and, ideally, our dataset should have an error below 10 feet. We were concerned, however, that this level of dissimilarity between the two datasets could be a result of errors in the post processing of the LIDAR data associated with vegetation canopy returns. For this reason, we used a bare earth/open field subset. This returned a more satisfactory value of 6.9 feet. While this error is still somewhat large, it is within the desirable margin of error for an elevation dataset of this resolution.

### METHODS

To complete the project, we divided the production process into six primary steps: Data preparation, TIN generation, TIN to DEM conversion, DEM hydrological enhancement, quality control and edge checking to adjacent DEMs. Two main software applications were used to perform the conversion and editing tasks: We utilized ESRI ArcGIS software for pre-processing the elevation and hydrographic SAMB vector files, for generating the terrain surfaces and for the QC processes. Titan Corporation’s Delta3D software was used for enhancing surface drainage, edge checking adjacent DEMs, DEM repair and additional QC.

Most of the procedures for creating the terrain surfaces were automated. WVGISTC created ArcGIS python and arc macro language (AML) programming scripts to automate all of the procedures required to create TIN and DEM terrain surfaces. In order to expedite the use of Delta3D DEM editing software, USGS provided WVGISTC with a combination of automated scripts and manual editing routines to enhance the surface drainage. USGS also provided processes used to correct errors in the DEMs and on the DEM edges. The completed 3-meter DEMs correspond in geographic extent to the USGS 7.5-minute topographic map series in West Virginia.

The elevation source data was provided to the WVGISTC in Microstation .dgn format. This needed to be converted into ESRI shapefiles (.shp), each containing points and polylines. Once in .shp format, the data projection was defined as State Plane (North or South) in feet, and then re-projected into UTM NAD83.

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**November 6 – 10, 2006 * San Antonio, Texas**
Using the 3D Analyst extension for ESRI Arc Toolbox, the Create TIN command was used to create an empty TIN. Adding the points (Figure 1a) and breaklines (Figure 2a) from a SAMB tile, the terrain features begin to take form (Figures 1b and 2b). Arc creates TIN faces using Delaunay Triangulation. The Delaunay Triangulation method optimizes the interior angles created from points so that the triangles are as equilateral as possible (Zeiler, 1999). This method avoids creating sliver triangles.

![Figure 1](image1.png) ![Figure 2](image2.png)

**Figure 1 (a).** 1 10,000ft by 10,000ft tile of mass points. **(b)** Mass points from figure 1 (a) directly converted to a TIN using ArcToolbox.

**Figure 2 (a).** 3D breaklines for 1 SAMB Tile. **(b)** Breaklines from figure 2 (a) added to the TIN from figure 1 (b).

Hydrological features such as streams, rivers and water bodies were then added to complete the TIN. Figures 3(a) and (b) show a detailed view of two streams (running horizontally) being crossed by an unknown feature (running vertically). Figure 3(a) has not been corrected for hydrologic features, while Figure 3(b) has. Note the cut through the unknown vertical feature. This process was used to enhance the hydrological drainage of the dataset, a requirement of the National Elevation Dataset.
Following hydrologic correction, each tile was then converted to an ESRI grid with 3 meter cells using the TINLATTICE command in Arc. The WVGISTC used the Quintic interpolation option in the TINLATTICE command because it appears to be more realistic in how it interpolates terrain features. The smoothing properties are less aggressive than that of the natural neighbor, while providing a greater smoothing than linear interpolation. Quintic interpolation does have some smoothing effects which helped dissolve some triangular faces, but does not show a significant loss of detail in the terrain features. Stream lines and pond boundaries are kept intact, and hillsides appear to be natural, though some triangular artifacts are still present.
Once the TIN was created from ArcGIS, it was converted to a USGS DEM format for export to Delta 3D. This step also created a rough bounding 7.5 minute quad. Once the DEM was loaded into Delta 3D, the quad was then processed for hydrologic enhancement. The hydro enhancement process was completed using semi-automated tools and additional manual processes in Delta 3D. The hydro enhancement and visual QC steps were the most labor intensive part of the project. Once the DEM had been processed through Delta 3D, it was visually inspected in Delta 3D for errors and unburned streams. The quadrangle was then exported for final QC and shipment to USGS.

After Delta 3D processing, the DEM was then brought into ESRI ArcMap and ArcScene for an additional round of QC. The quads at this stage were then checked for elevation high and low value in addition to edge matching. Once a quad was approved, they were batch shipped to USGS for final QC and ultimately integrated into the NED and the Seamless Data Distribution Website.
DISCUSSION

It should be noted that the 3 meter cell resolution exceeds the maximum supported resolution of the mass point and breakline source data, which was only intended to support 5 meter cell resolution. This "exaggeration" was decided to be more acceptable than downsampling the data to 1/3rd arc-second, which would have resulted in a major loss of information. Because of the over-sampling, the resultant grids show triangle artifacts from the faces of up the TIN. Nonetheless, because the raster was created directly from the source point and breakline data, the USGS in conjunction with WVGISTC, determined that the resultant data was accurate and acceptable at the 1/9th arc second level.

Continued Projects and Uses

The data will serve in planned follow-up projects at the WVGISTC including the delineation of improved watershed boundaries and in the conflation of the state’s National Hydrographic Dataset to 1:4800 scale (local resolution).

This high resolution elevation data has already been used in multiple applications including wastewater treatment analysis by the Canaan Valley Institute and mine permitting by the West Virginia Department of Environmental Protection. In addition, FEMA will use the data as input to the Flood Insurance Rate Map modernization effort. The Census Bureau will also use the data to readjust block boundaries defined along ridgelines in many parts of the state. Many other GIS services and benefits for the citizens of the Mountain State are anticipated from use of the new elevation data.

ACKNOWLEDGEMENTS

Special recognition is given to the Statewide Addressing and Mapping Board and West Virginia Division of Highways, which provided the statewide elevation data to WVGISTC for the vector-to-raster
conversion. In addition, the USGS should be acknowledged for funding this project and for their technical support to make this conversion project successful. Finally, principal contributors of the WV GIS Technical Center are Kurt Donaldson, Evan Fedorko, Kevin Kuhn, and Xuan Shi.

REFERENCES


APPENDIX A

- Statewide Addressing and Mapping Board – http://www.addressingwv.org
- WV GIS Technical Center – http://www.wvgis.wvu.edu/
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