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Feature Extraction from High-Resolution Lidar: the Next Generation of Base Maps

By Jed T. Roberts

Oregon Department of Geology and Mineral Industries
800 NE Oregon Street, Suite 965
Portland, OR 97232
Telephone: (971) 673-1546
Fax: (971) 673-1562
email: jed.roberts@dogami.state.or.us

INTRODUCTION

The Oregon Department of Geology and Mineral Industries (DOGAMI) is the founding and primary member of the Oregon Lidar Consortium (OLC). The OLC has acquired approximately 4,000 square miles of publicly licensed, high resolution lidar topography in Oregon as of May, 2009, and will have more than doubled that coverage by the end of the calendar year.

DOGAMI is the state agency charged with producing maps and reports of geologic phenomena and risk associated with natural hazards, such as tsunamis, landslides, coastal erosion, riverine floods, earthquakes, and volcanics. In an effort to produce work of the highest possible quality, virtually no new mapping of geology or natural hazards is undertaken without complete lidar coverage. While recently acquired lidar is beneficial in most cases, it does cause problems when producing base maps on which to present geologic and natural hazard data. The fundamental problem is that lidar is much more spatially accurate than other data sources and that when thematic layers are overlaid, misalignments abound. Some initial solutions are proposed by Burns (2008). The following is a description of several advanced methods for extracting thematic layers directly from the lidar.

BARE EARTH DEM

Raw Elevation Model

The bare earth digital elevation model (DEM) is a representation of the Earth's surface stripped of man-made objects and vegetation (Figure 1). This is achieved through post-processing of lidar point data, where the sheer density of elevation points collected -- in this case, upwards of 8 points per square meter -- allows for the recognition of high-precision (sub-meter) ground trends. Within the geology community, bare earth elevation models have proven revolutionary in their ability to reveal the subtleties of terrain, shedding light on previously unidentified features such as alluvial fans, landslides, and historical channel beds. The power of the bare earth elevation model to aid in understanding terrain is further examined here through various strategies in geovisualization.

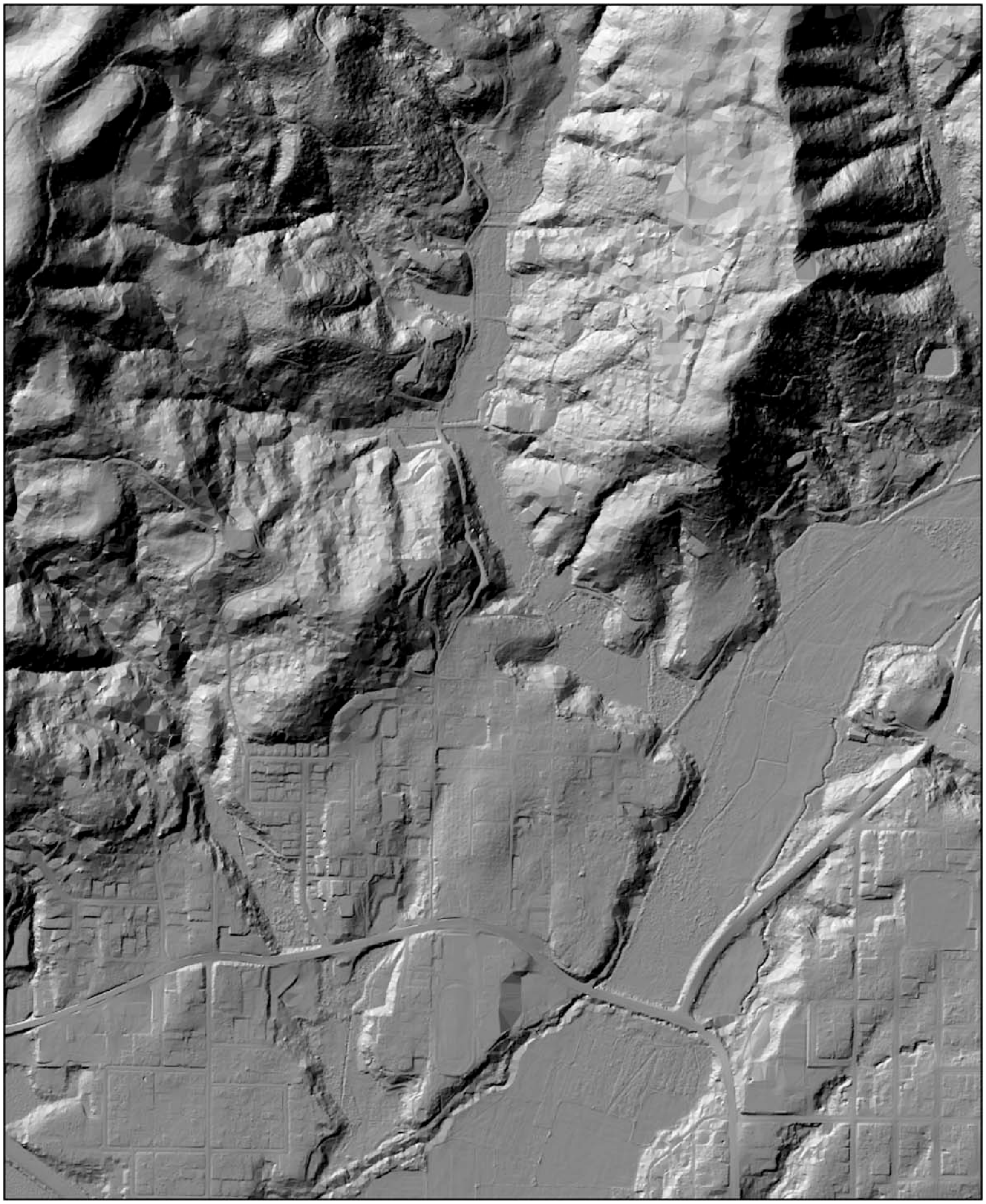
Figure 1. Bare earth lidar with standard hillshading (315 degrees azimuth and 45 degrees declination). The area featured here is a portion of the city of Coquille, Oregon.

Customized Hillshading

Hillshading brings an elevation model to life. However, every terrain is unique, so why illuminate them all the same way? In this example we shift the light source from its standard 315 degrees azimuth and 45 degrees declination to 345 and 60, respectively (Figure 2). Also, we exaggerated the vertical by a factor of 5. This landscape is dominated by northwest trending drainages, and so specifying the light source further northward better defines their features. Exaggerating the elevation in an area with such high relief also helps to bring out its nuances.

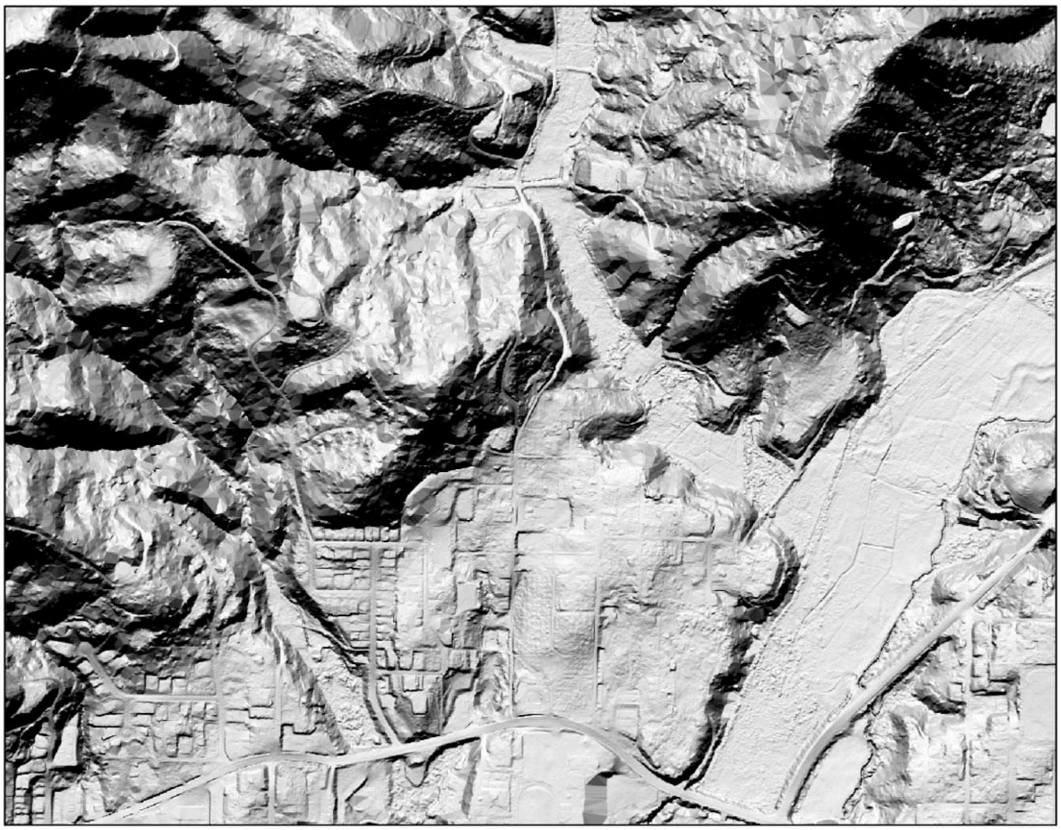

Figure 2. Bare earth lidar with customized hillshading (345 degrees azimuth and 60 degrees declination, and 5X vertical exaggeration).

Defined Slopes

While hillshading is truly essential for visualizing terrain, its inherent directional biases often shroud useful detail that lies in shadow. An effective method for accenting all slopes is by draping a semi-transparent hillshade over a slope layer, where the highest slope values are represented by a dark color (Figure 3). It is also useful to exclude low slope values when classifying your slope layer, since they are not especially useful and have a tendency to muddy up the look of your map.

Figure 3. Bare earth lidar with customized hillshading and defined slopes.

Smoothed Contours

Contours minimize guesswork when interpreting elevations. With lidar it is possible to effectively contour a terrain with 2 foot intervals. At smaller scales, though, such exquisite detail becomes a visual liability. To massage out some of this detail and produce more appealing and appropriate contours, try smoothing your bare earth elevation model by averaging its values over a set radius, and then build your contours from there. These contours have an interval of 20 feet with indices every 100 feet (Figure 4).

Figure 4. Bare earth lidar with customized hillshading, defined slopes, and smoothed contours.

Hydrology Delineation

Numerous valiant attempts have been made toward automating the extraction of hydrologic features from lidar. Nonetheless, we find that there is no substitute for the trained eye and a steady hand. Using a combination of bare earth hillshade and slope as a base layer produces accurate stream and water body delineations on the first try, with no clean-up of erroneous (and often ample) vertices (Figures 5 and 6). Ortho-rectified aerial photos can be used to verify hydrologic features where they are unclear in the lidar.

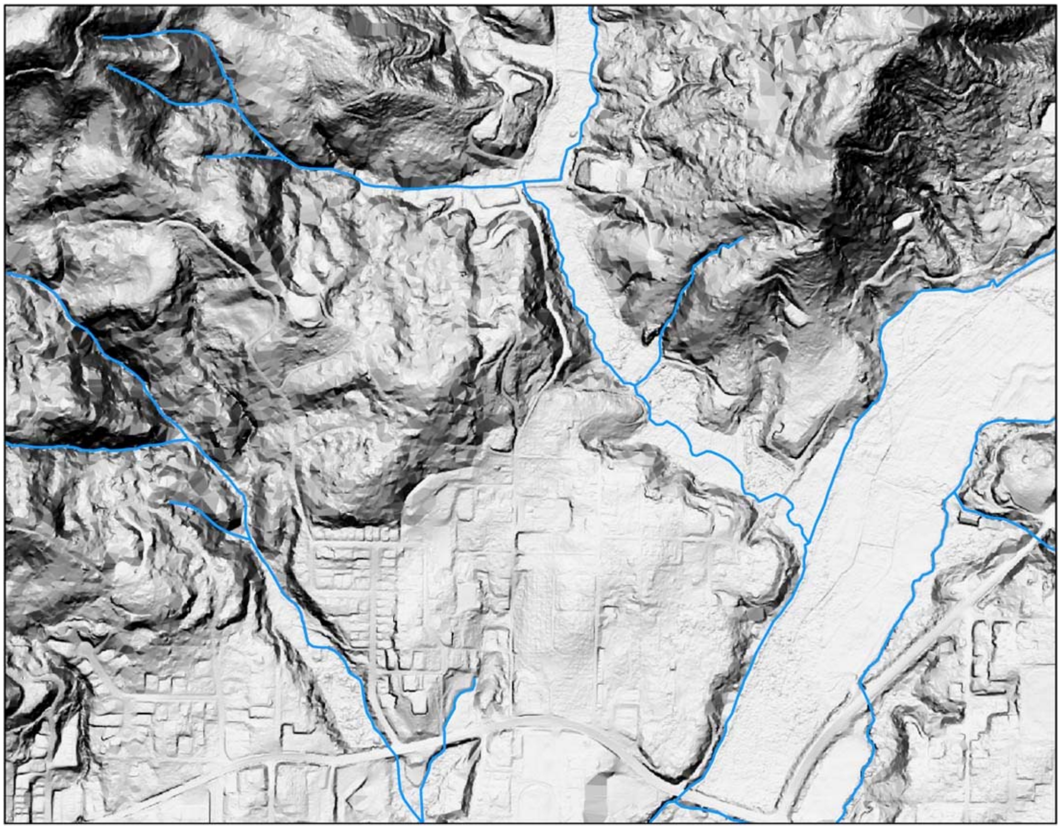

Figure 5. Bare earth lidar with customized hillshading, defined slopes, and hydrology (blue lines).

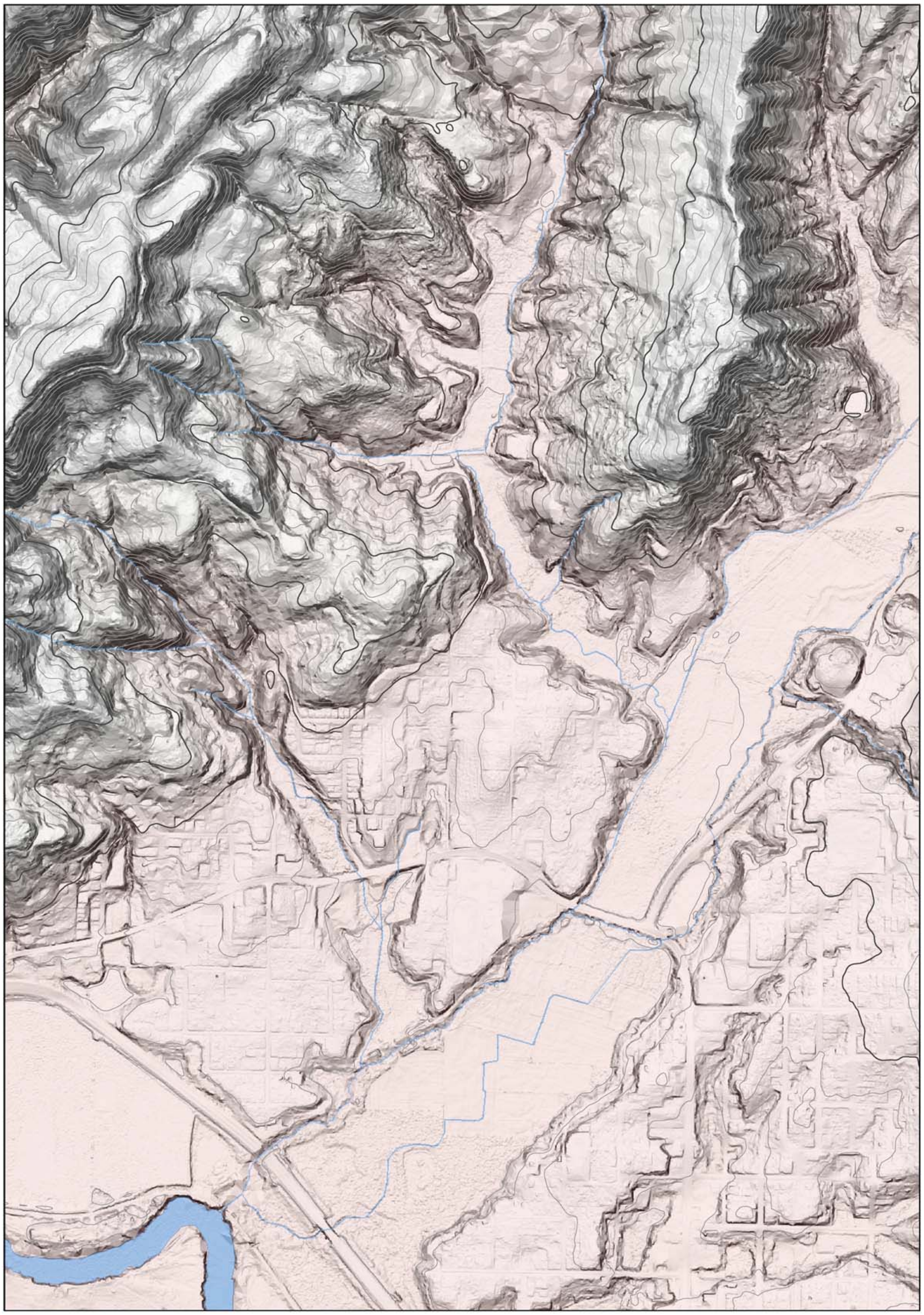

Figure 6. Composite bare earth lidar image.

HIGHEST-HIT DEM

Raw Elevation Model

The highest-hit elevation model is a representation of the full-featured landscape at the time of the lidar aerial survey (Figure 7). As opposed to the last-return (ground) illustrated by the bare earth elevation model, the highest-hit is the first-return to the lidar sensor -- be it tree, car, skyscraper, or even people. Though not as immediately useful for applications in geology as the bare earth elevation model, it has many merits when it comes to feature extraction for base mapping.

Figure 7. Highest lidar with standard hillshading.

Structure Modeling

With some simple math we can approximate flat-topped structures (e.g. buildings). First we subtract bare earth from highest hit. This gives us the heights of all raster cells considered "non-ground." We can further refine this by taking the slope of our "non-ground" layer and isolating those areas with low slopes -- say below 25 degrees. In general, these areas will represent buildings and bridges (Figure 8). Additional tricks in symbology can be employed to reduce the appearance of non-buildings.

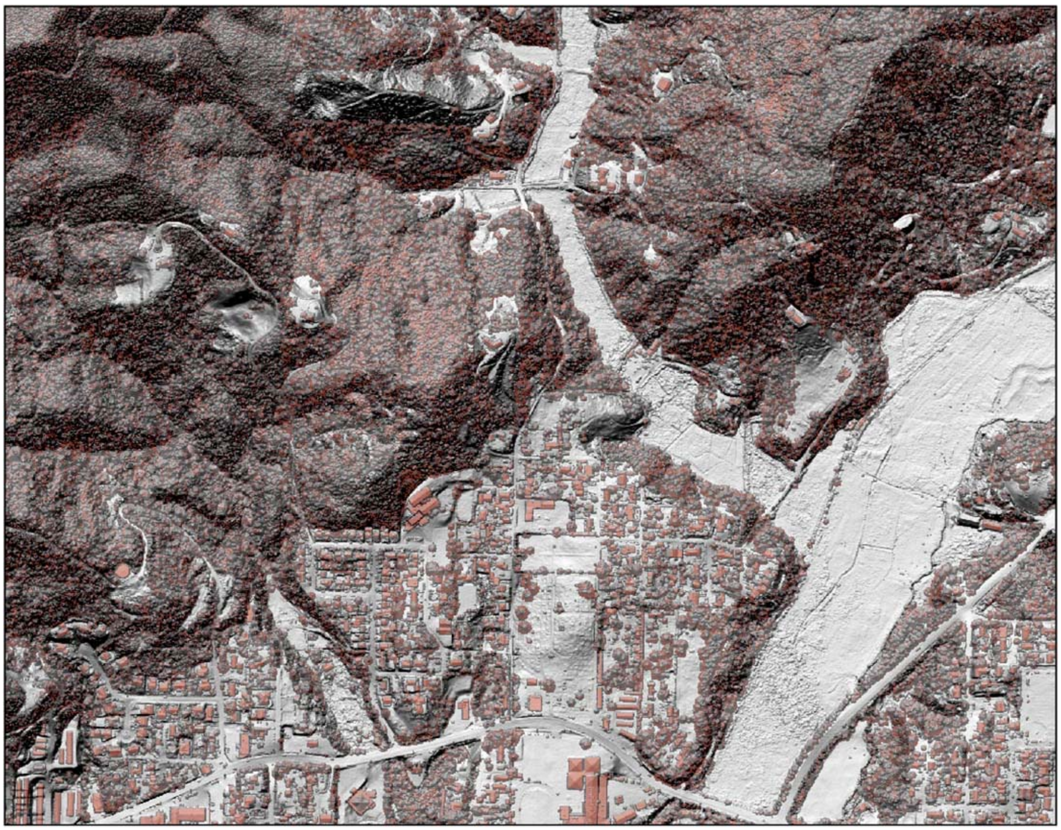

Figure 8. Highest lidar with customized hillshading and structure model.

Canopy Modeling

Similar to structure modeling, using a "non-ground" layer we can approximate trees and other vegetation. This time we are interested in isolating features with a rather high slope. We can then take one step further by symbolizing "non-ground" height values from a light green (shrubs) to a dark green (tall trees). The result is a very visually appealing layer that illustrates the varying heights of trees in particularly well forested landscapes (Figure 9).

Figure 9. Highest lidar with customized hillshading and canopy model.

Building Extraction

Structure modeling can be further extended to true building extraction. With the help of Lidar Analyst software (by Visual Learning Systems) we can create polygons that accurately represent building footprints with very little or no editing. Lidar Analyst uses breaks in slope, recognition of angles, and supervised classification to produce polygons that are attributed with z-values -- very useful for 3D visualizations. This tool, in concert with structure and canopy modeling, creates an extremely realistic view of a landscape without use of aerial photos (Figures 10 and 11). It is worth noting that building extraction differs from hydrologic feature extraction in that the resultant vector layer is much less vertex-rich, and therefore less painstakingly edited.

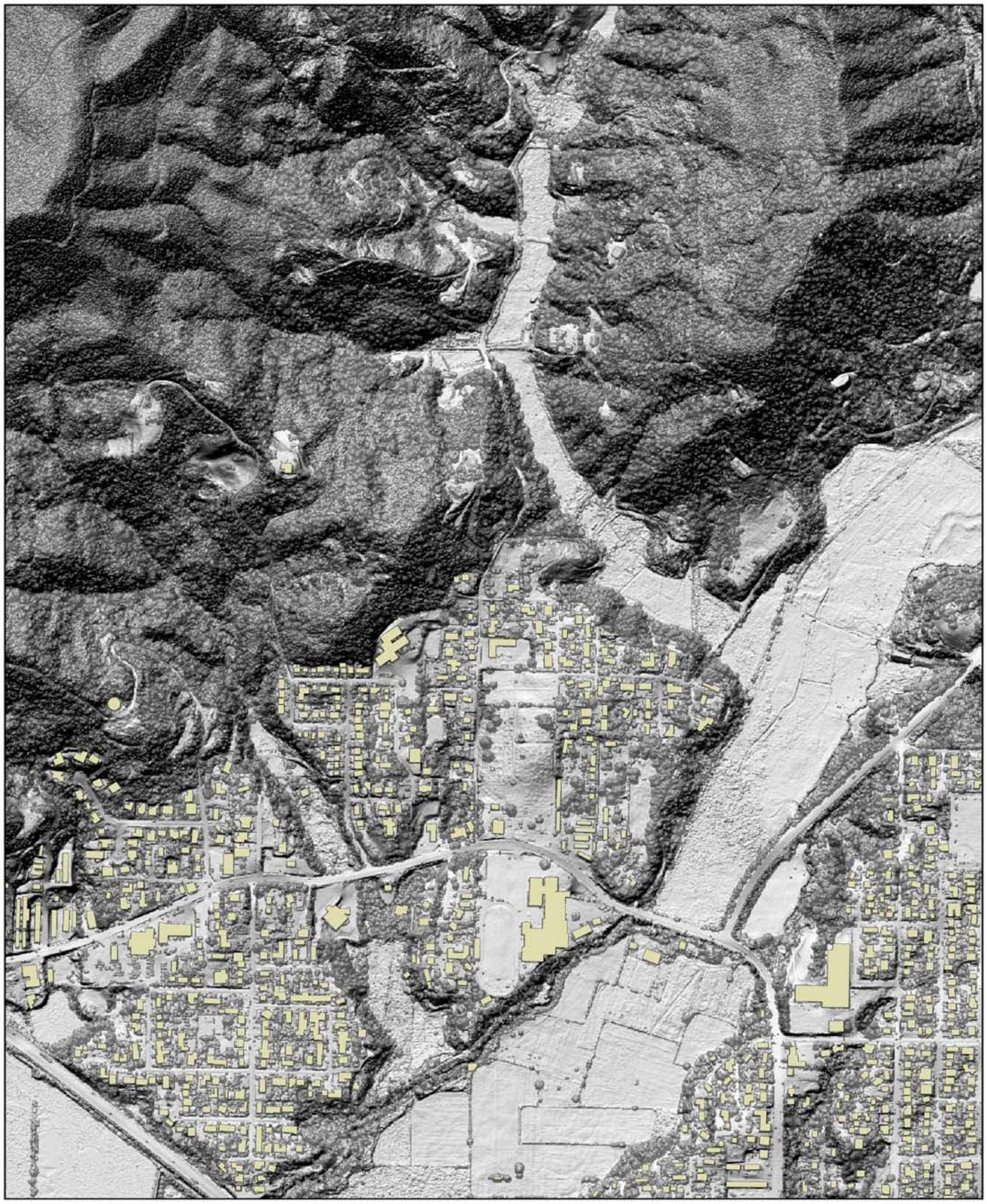

Figure 10. Highest lidar with customized hillshading and extracted buildings (in yellow).

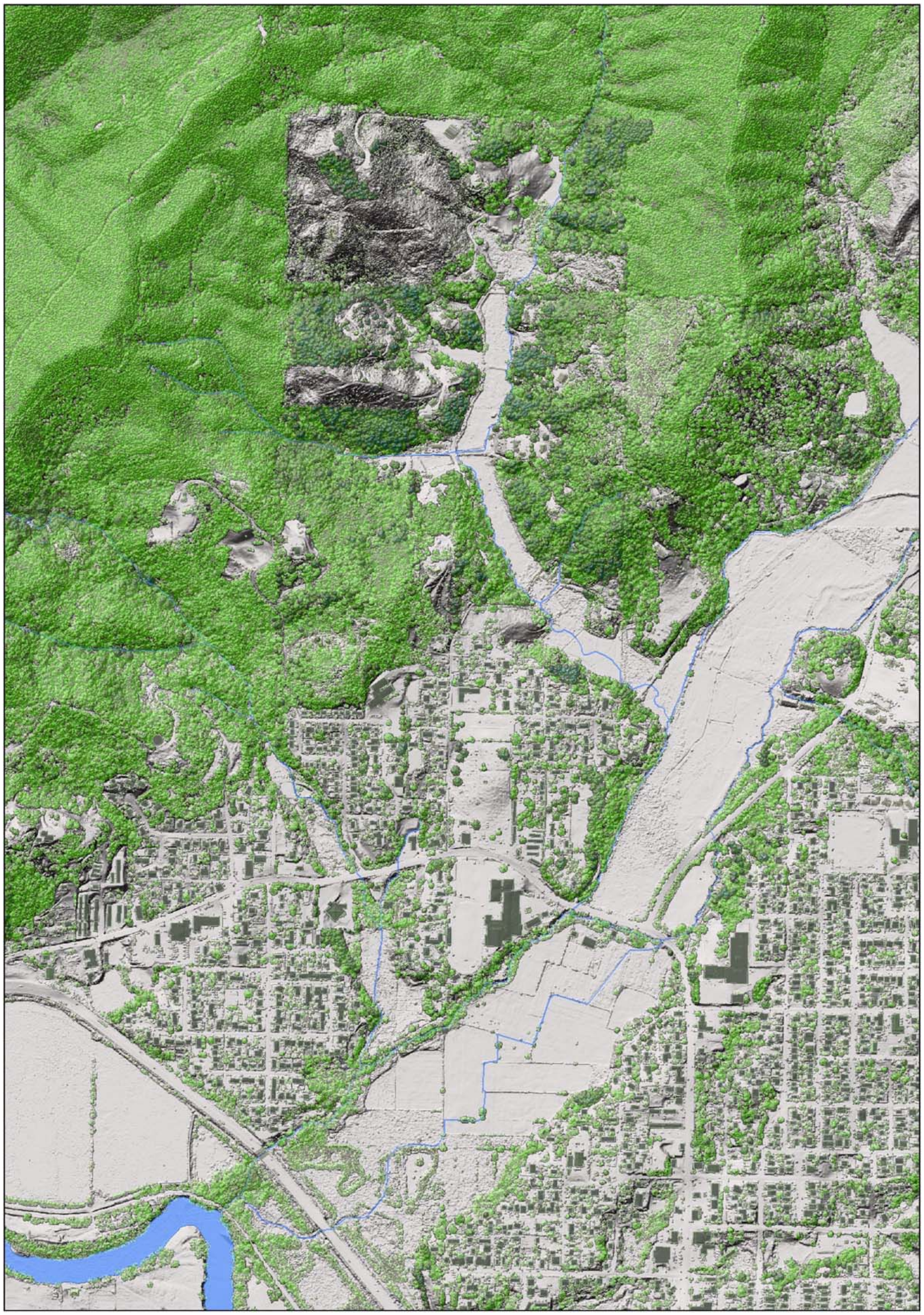

Figure 11. Composite highest hit lidar image (with extracted buildings, not structure model).

ADDITIONAL NOTES

These data were collected with a Leica ALS50 Phase II Lidar system (150 kHz). Pulse density is at least 8 points per square meter with vertical accuracies within 15 centimeters on flat surfaces. Raw data were gridded to 1-meter resolution. The town of Coquille, Oregon is shown on these maps. All maps are represented at a scale of 1:8,000. Maps projected in Universal Transverse Mercator (NAD 1983) Zone 10 North. All geoprocessing was performed using ESRI ArcGIS products.

REFERENCE

Burns, W.J., 2008, Regional landslide hazard maps of the southwest quarter of the Beaverton Quadrangle, West Bull Mountain Planning Area, Washington County, Oregon: Oregon Department of Geology and Mineral Industries, Open File Report O-08-09.