Coastal and Marine Geology Program

Hydrologic Enforcement of Lidar DEMs

Hydrologic-enforcement (hydro-enforcement) of light detection and ranging (lidar)-derived digital elevation models (DEMs) modifies the elevations of artificial impediments (such as road fills or railroad grades) to simulate how man-made drainage structures such as culverts or bridges allow continuous downslope flow. Lidar-derived DEMs contain an extremely high level of topographic detail; thus, hydro-enforced lidar-derived DEMS are essential to the U.S. Geological Survey (USGS) for complex modeling of riverine flow. The USGS Coastal and Marine Geology Program (CMGP) is integrating hydro-enforced lidar-derived DEMs (land elevation) and lidar-derived bathymetry (water depth) to enhance storm surge modeling in vulnerable coastal zones.

Hydrologic Lidar DEMs

Light detection and ranging (lidar)-derived digital elevation models (DEMs) often present challenges for hydrologic modeling, as they typically include features such as road fill and railroad grade overlaying culverts, bridges, and other raised surfaces that impede the natural flow of surface water (fig. 1*A*). Water is carried through these features that cannot be represented in a lidar-derived topographic DEM. A lidar-derived hydrologic DEM representing the actual water flow surface is required for any hydrologic modeling (fig. 1*B*).

The process of modifying topographic DEMs to hydrologic DEMs is not new, but the extreme detail of lidar-derived topographic DEMs creates special challenges in identifying the numerous features captured in these lidar-derived topographic DEM datasets. A novel method for locating features and modifying elevations for hydrologic-enforcement (hydro-enforcement) was used in water-related modeling in the Delaware River watershed (Poppenga and others, 2014).

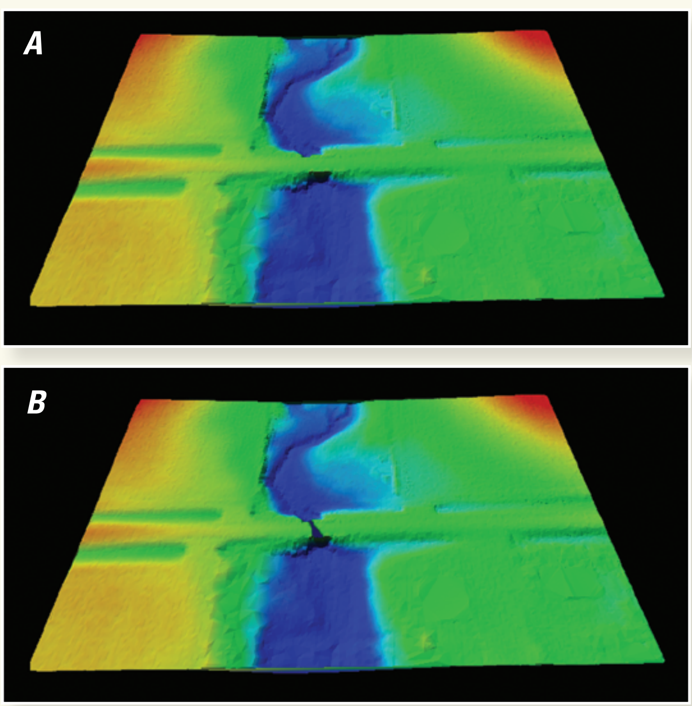

Figure 1. Surfaces showing *A*, Topographic DEM with road fill over a culvert and *B*, Hydrologic DEM with hydro-enforcement at the culvert location.

Hydro-Enforced Lidar DEMs

Hydro-enforcement of lidar-derived topographic DEMs enables hydrologic models to simulate flow under bridges and through culverts. Without hydro-enforcement, downslope flow would be functionally dammed by the raised topography, creating false pooling on the upstream side (Poppenga and others, 2010, 2012, 2013; Heidemann, 2012).

Effective hydrologic modeling using lidar-derived topographic DEMs requires a single hydro-enforced DEM for an entire study area. Unfortunately, the extents of lidar point cloud data acquisitions typically are based on political, rather than watershed boundaries; and the most commonly delivered is the traditional topographic DEM. As a result, multiple topographic DEMs must be merged into a single surface before hydro-enforcement. For a part of the Delaware River watershed in New Jersey and Pennsylvania, three different airborne lidar datasets, collected between 2006 and 2009, were processed and mosaicked into a single high-resolution topographic DEM (fig. 2). The resulting 23 gigabyte lidar-derived topographic

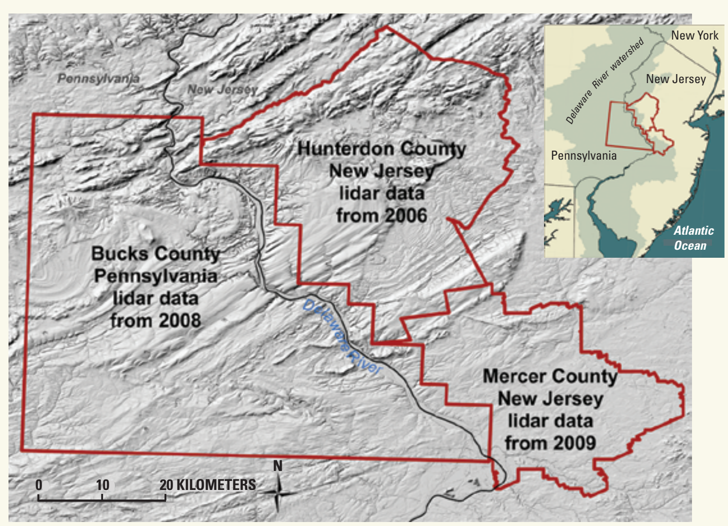

Figure 2. Map of lidar-derived DEMs in New Jersey and Pennsylvania mosaicked as a high-resolution topographic DEM that was used to generate the hydrologic DEM.

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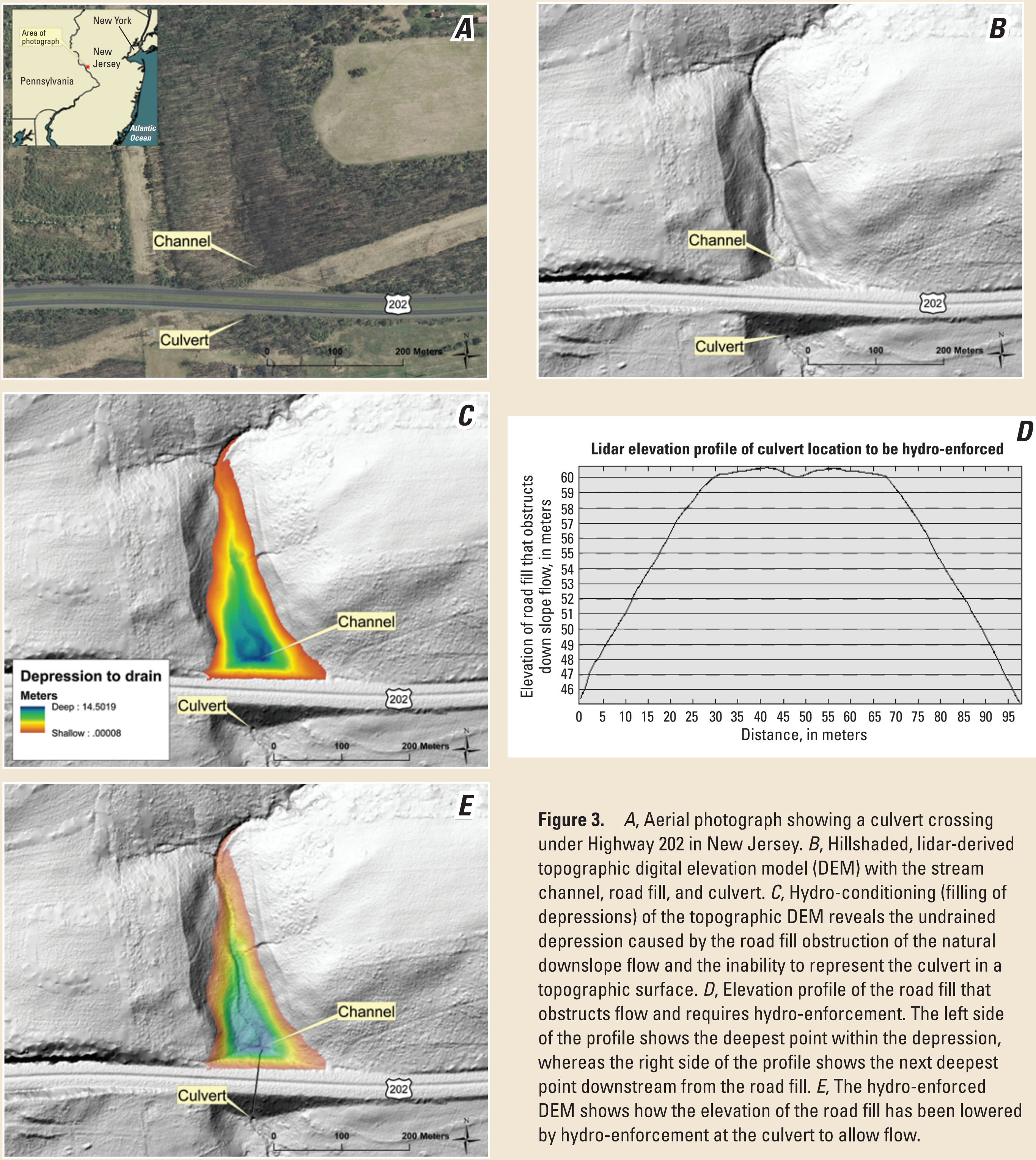

Figure 3. *A*, Aerial photograph showing a culvert crossing under Highway 202 in New Jersey. *B*, Hillshaded, lidar-derived topographic digital elevation model (DEM) with the stream channel, road fill, and culvert. *C*, Hydro-conditioning (filling of depressions) of the topographic DEM reveals the undrained depression caused by the road fill obstruction of the natural downslope flow and the inability to represent the culvert in a topographic surface. *D*, Elevation profile of the road fill that obstructs flow and requires hydro-enforcement. The left side of the profile shows the deepest point within the depression, whereas the right side of the profile shows the next deepest point downstream from the road fill. *E*, The hydro-enforced DEM shows how the elevation of the road fill has been lowered by hydro-enforcement at the culvert to allow flow.

DEM was then used as the foundation layer for hydro-enforcement (Poppenga and others, 2014).

As the first step of the hydro-enforcement process, drainage methods were used to isolate impediments to downslope flow and establish appropriate elevations for subsequent revisions to the topographic DEM. The drainage methods consisted of hydro-conditioning (or filling) the lidar-derived topographic DEM to define undrained depressions by calculating residuals between the filled and unfilled lidar-derived topographic DEM (Poppenga and others, 2010, 2012). The elevation revisions consisted of adjusting elevation values for structures (culverts and bridges) in the lidar-derived topographic DEM that artificially prevent downslope flow across the DEM.

For example, figure 3*A* shows a channel near a road fill that overlies a culvert. In figure 3*B*, the lidar-derived topographic DEM shows that the road fill would block downslope flow and create an undrained depression on this DEM surface, as shown in figure 3*C*. In reality this depression is drained by the culvert. The undrained depression contains elevation values that represent depth (fig. 3*C*). Typically, the deepest point in a depression such as this indicates culvert inflow and a starting point for hydro-enforcement. The elevation profile (fig. 3*D*) shows the deepest point of the depression upstream from the culvert (left side of the profile) and also shows the change in elevation to the next deepest downslope location on the other side of the road fill (right side of the profile). In the lidar-derived topographic DEM, the road fill obscures the underlying culvert, which functionally removes the actual drainage path from the upstream depression (fig. 3*C*). The lidar-derived topographic DEM then will be hydro-enforced at this location to allow downslope drainage. Figure 3*E* depicts the hydrologic DEM that is the result of hydro-enforcement. The elevation of the road fill near the culvert has been changed to the same elevation of the deepest point in the depression.

Filling (hydro-conditioning) undrained depressions in the topographic DEM (fig. 3*C*) reveals locations where downslope flow is impeded, typically road fills over culverts, and provides elevations where hydro-enforcement of the topographic DEMs are needed. The hydrologic DEM (fig. 3*E*) can then be incorporated into topobathymetric datasets used in hydrodynamic models.

Hydro-Enforced Topobathymetric DEMs

The boundaries between land and water (land/water interface) typically contain critical coastal ecosystems that are affected by land change. To better understand these sensitive landscapes, consistent elevation and topobathymetric datasets are important and needed to map coastal land/water interfaces. Because ships cannot operate close to the shore while soundings for water depth (bathymetry) are collected, optical sensors, such as lidar, are used for near-shore bathymetric collections.

By merging lidar-derived topographic DEMs (land elevation) and bathymetry (water depth), a three-dimensional topobathymetric DEM can be developed to analyze topographic and structural features along the land/water interface (fig. 4). Topobathymetric DEMs provide a seamless elevation surface that is useful for water inundation mapping, as well as other earth science applications, such as the development of sediment-transport, sea-level rise, and storm surge models (Danielson and others, 2013). To further enhance topobathymetric DEMs, hydro-enforced land-elevation data (fig. 3*E*) are incorporated into topobathymetric DEMs (fig. 4). These data are important in complex riverine flow and storm surge modeling in vulnerable land/water interfaces along coastal zones.

The integration of different hydro-enforced DEMs from airborne- and ground-based lidar datasets, hydrographic sounding (acoustic) surveys, and lidar-derived bathymetric datasets creates a final fused DEM that seamlessly extends information across critical coastal ecosystem boundaries.

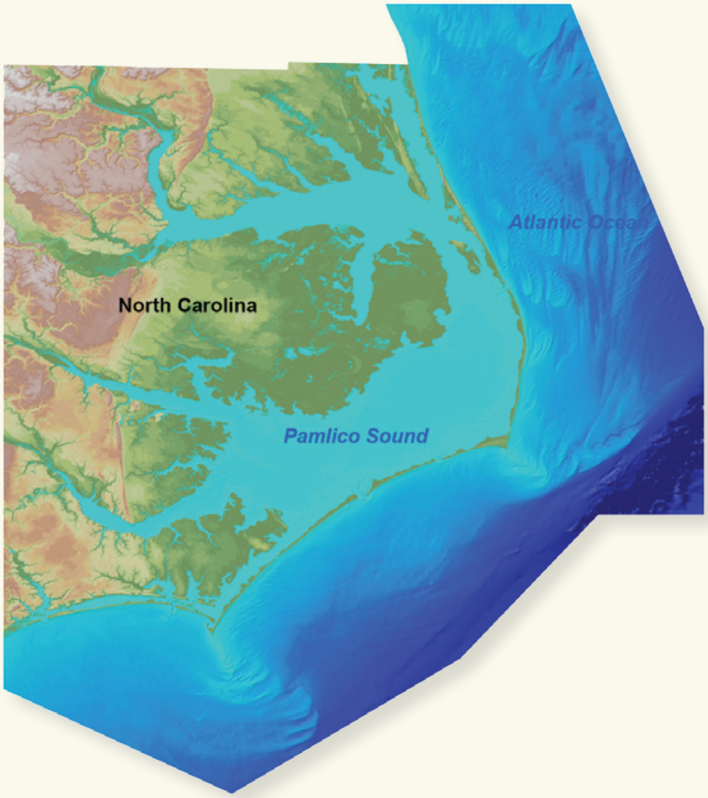

Figure 4. Topobathymetric digital elevation model (DEM) of the North Carolina land/water interface (Tyler, 2013). The lidar-derived land elevation data (topography) and water depth (bathymetry) data collected from soundings and near-shore lidar data collection provide information needed to create this topobathymetric DEM.

Hydro-Enforced Topobathymetric DEMs for the Coastal National Elevation Database (CoNED)

The region that was affected by Hurricane Sandy, along with much of the Atlantic and Gulf coastal regions of the United States, is vulnerable to the effects of hurricanes. These coastal regions lack the comprehensive integrated onshore-offshore baseline elevation data required for hazard mitigation policies, redevelopment planning, and emergency preparedness and disaster response (Buxton, and others, 2013; Stronko, 2013).

The Sandy Region Coastal National Elevation Database (CoNED) Project aims to construct a regional topobathymetric elevation database for the entire Sandy impact region with enhanced vertical accuracy within low-lying extreme inundation hazard zones. The Sandy Region CoNED database will merge high-resolution, hydro-enforced DEMs from multiple lidar datasets; the database will contain topobathymetric elevation data that extend over vulnerable urbanized areas, and include dynamic coastal regions.

The CoNED regional topobathymetric elevation database and related derivatives for the entire Sandy impact region will help with the recovery of Hurricane Sandy. Other uses of this database and related derivatives include assessing coastal landscape change and vulnerability; designing restoration, redevelopment, and protection projects; predicting future hurricane-storm surges, coastal and inland flooding and; devising strategies for climate-change adaptation from sea-level rise (Buxton, and others, 2013; Stronko, 2013).

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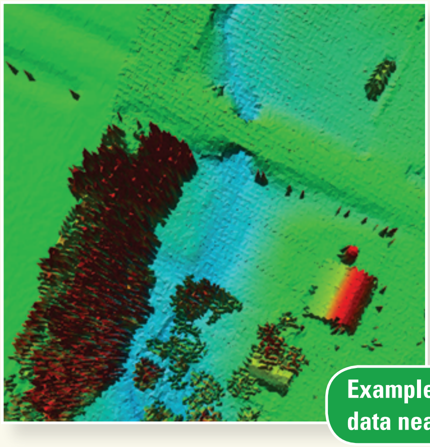

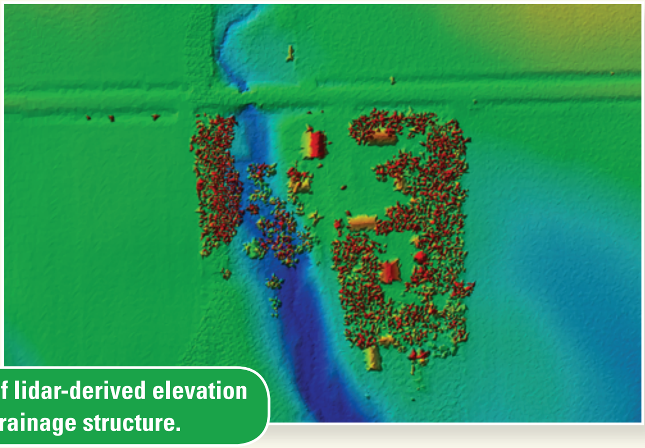

Examples of lidar-derived elevation data near drainage structure.

Contact Information

Sandra K. Poppenga
Topographic Science
USGS Earth Resources Observation and Science (EROS) Center
47914 252nd Street
Sioux Falls, SD 57198
spoppenga@usgs.gov
http://topotools.cr.usgs.gov

Jeffrey J. Danielson
Topographic Science
USGS Earth Resources Observation and Science (EROS) Center
47914 252nd Street
Sioux Falls, SD 57198
daniels@usgs.gov
http://topotools.cr.usgs.gov

John C. Brock
Coastal and Marine Geology Program
USGS National Center
12201 Sunrise Valley Drive
Reston, VA 20192
jbrock@usgs.gov
http://marine.usgs.gov