DIGITAL TERRAIN MODELING FOR FLOODPLAIN MODELING AND MAPPING

Primary Author: Sam Crampton, Chairman: Georgia Association of Floodplain Management, GIS Mapping and Technical Committee; scrampton@dewberry.com

The falling cost of acquiring digital terrain data from remote sensing has enabled a technical revolution to occur for floodplain managers, mappers and modelers. Almost all metropolitan counties and some rural counties now have digital topography that far exceeds the quality of the USGS topographic quads and digital elevation models that were traditionally used by floodplain managers.

Despite the availability of data, there is still a need for a greater understanding of this data, its advantages, limitations, quality and standards required for different uses.

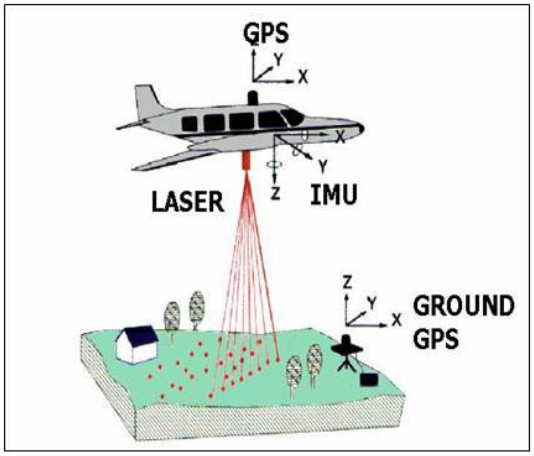
Since the last technical conference of the GAFM, the GIS Mapping and Technical Committee has embarked on a project to help members develop a greater understanding of a whole range of topics related to digital terrain modeling. The committee has worked with a range of groups and individuals including aerial surveyors, community GIS and stormwater departments, and private consultants to develop a presentation and white paper to help floodplain managers gain a better understanding of all aspects of floodplain management related to digital terrain modeling.

METHODS FOR COLLECTING DIGITAL TERRAIN DATA

The two most common methods of remotely collecting digital terrain data are Photogrammetry and Light Detection and Ranging (LiDAR). Both can be used independently to develop digital terrain data although often they can complement each other to provide an improved product.

Photogrammetry is a measurement technology in which the three-dimensional coordinates of points on an object are determined by measurements made in two or more photographic images taken from different positions. Common points are identified on each image. A line of sight (or ray) can be constructed from the camera location to the point on the object. It is the intersection of these rays (triangulation) that determines the three-dimensional location of the point. Although photogrammetry can be performed from anywhere where a camera can be used, data used by floodplain managers will usually be collected using aircraft.

Light Detection and Ranging (LiDAR) is a system for gathering digital terrain data using airborne laser systems flown aboard an aircraft equipped with GPS. The laser system is used to determine distances and angles to the ground which can determine x, y and z coordinates of both manmade and naturally occurring terrain and terrain features. LiDAR determines the distance between the origin of the beam and the target in a similar manner to radar technology, which uses radio waves instead of laser to determine the range to an object by measuring the time delay between the transmission of a pulse and detection of the reflected signal.



REQUIREMENTS FOR FEMA FLOOD STUDIES

Guidance for digital terrain data collection has been incorporated into Appendix A of the Guidelines and Specifications for Flood Hazard Mapping Partners.

FEMA defines its topographic data accuracy requirements in map scale and contour intervals equivalent to the National Map Accuracy Standard (NMAS).

FEMA defines two general categories for vertical accuracy of digital terrain data:

Two-Foot Equivalent – This is data that has an accuracy of ±1.2 feet (36.5cm) at the 95% confidence interval (ie 95% of data points have an accuracy with respect to the true ground elevation equal to 1.2 feet or smaller)

Four-Foot Equivalent – This is data that has an accuracy of ±2.4 feet (73.2 cm) at the 95% confidence interval (ie 95% of data points have an accuracy with respect to the true ground elevation equal to 2.4 feet or smaller)

Two-Foot Equivalent data is generally required for modeling and mapping areas of flat terrain, particularly where closed basin modeling is required. Four-Foot Equivalent data is generally acceptable where there is moderate to steep terrain. Generally, in Georgia, 4 ft topographic data would be acceptable. The only areas where 4 ft topographic data may not be suitable would be the flat coastal plain areas along Georgia's relatively small coastline. Despite this requirement, with modern LiDAR and photogrammetry technology, rarely is data ever captured to a quality of less than 2-foot equivalent.

The required horizontal accuracy of digital terrain data is a function of the intended map panel scale. The following radial horizontal RMSE values and accuracies are required for certain map panel scales:

Map Scale	**NSSDA RMSE (ft)**	**NSSDA Accuracy, 95% Confidence Level**
1" = 500'	11	19.0
1" = 1000'	22	38.0
1" = 2000'	26.3	45.6

When only data of a lesser standard is available, the Regional Project Officer or Project Officer for FEMA may accept a lower standard if it can be demonstrated that it is the best available data and is likely to produce improved results from any effective studies.

DIGITAL TERRAIN DATA FORMATS

Digital terrain data is often supplied as mass points and may contain breaklines if required in either a spatial file or as an ASCII text file defining x, y, z coordinates for points and breakline vertices. Breaklines can be classified into two broad types:

Hard-Breaklines – These define sudden changes in terrain such as ridgelines

Soft-Breaklines – These ensure that an elevation is maintained along a smooth surface without interruptions in surface smoothness such as the centerline of a road

Contours are lines of equal elevation on a surface and are commonly used to provide a visual representation of digital terrain data. Delivery of digital terrain data will normally include digital contours as well as the mass points and breaklines.

Digital terrain data is often converted into a Digital Elevation Model (DEM), which is a continuous grid of regular intervals and has an elevation specified for each grid cell. Because of the gridded nature of DEMs, accuracy can often be diminished from the original data source and cannot be recreated exactly from the DEM. The accuracy of a DEM decreases with increased cell size and/or more rapidly varying terrain. The cell size of the DEM must be carefully selected for its intended purpose considering the variability of the terrain and the potential impacts of too large or too smaller grid cell sizes.

A Triangulated Irregular Network (TIN) is another commonly used format to display and analyze digital terrain data. A TIN is a set of adjacent, non-overlapping triangles computed from irregularly spaced points and breaklines and stores the topological relationship between triangles and their adjacent neighbor. Unlike a DEM they can maintain the exact features of their input data (original point and breaklines could be recreated exactly from a TIN). Because of this, TINs are often preferable to a DEM when it is critical to preserve the precise location of narrow or small surface features such as levees or stream channels.

DIGITAL TERRAIN DATA FOR RIVERINE HYDROLOGIC STUDIES

Digital terrain data when converted to a DEM can be used to automate watershed delineations using GIS with greater accuracy than the commonly used National Elevation Dataset (NED). This is particularly beneficial in very flat areas, which require closed basin hydrologic and hydraulic analysis. Care must be taken to hydro enforce any DEM used for automated watershed delineation because the occurrence of dams and roadway embankments can often be confused by applications as watershed ridgelines creating hydrologic errors in the watershed and flow line delineations. Watersheds and stream lines can be delineated using the principles of flow direction and flow accumulation where GIS is used to identify the flow direction of each individual cell in a DEM and then accumulates these flow directions to determine drainage area, watersheds and streamlines.

DIGITAL TERRAIN DATA FOR RIVERINE HYDRAULIC STUDIES

Traditionally ground surveys were used for cross sections in hydraulic models but due to limited budgets, only partial cross sections were surveyed requiring overbank areas to be determined from low accuracy USGS Quad maps. At the scoping stage of a hydraulic study, it is often impossible to determine every location where a cross section will be needed to achieve model stability. Therefore, when it was determined that more data was needed after the survey is complete and the models are nearing completion, it was often not feasible to collect new survey and so copied sections or interpolates were commonly used to achieve model stability.

The arrival of high accuracy digital terrain data has enabled partial survey sections to be extended using the digital terrain data with accuracy far greater than that experienced using USGS Quads and comparable to that achieved using ground survey. This has reduced the cost of ground surveys since only the channel portion of a model cross section is required by ground survey. During the modeling process when it is determined that additional sections are needed, these sections can be created from digital terrain without ground survey. Care must be taken when doing this because digital terrain datasets normally do not contain any sub water surface data and therefore field measurements or approximations are needed for the channel portions of the cross section.

At the floodplain mapping stage of a hydraulic study, the DTM can be used to accurately delineate the floodplains. The ability to automate floodplain delineations from the digital topography reduces the time and enables a more accurate delineation to be performed reducing the cost of a study. When using digital terrain data for automated hydrology and hydraulics, approximate floodplains can be redelineated for incorporation into a DFIRM at comparable expense to digital uplift. This is performed by automated hydrology and hydraulics giving the user a much higher quality product than the effective data that is likely to have been delineated from USGS Topographic Quadrangles. The higher accuracy achieved using high accuracy digital terrain data helps meet the standards required in FEMAs Procedure Memorandum 38 and the Floodplain Boundary Standards.

DIGITAL TERRAIN DATA FOR COASTAL FLOODING STUDIES

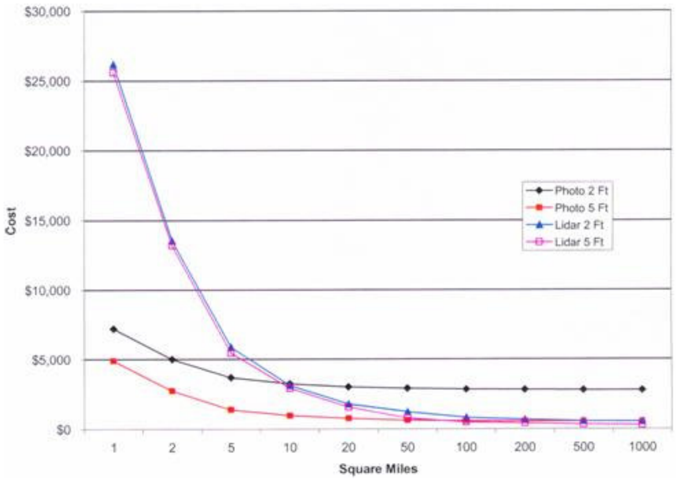
Historically, coastal modeling has relied heavily on the USGS Topographic Quadrangles, aerial photography, and field surveys to determine ground elevations, determine the location of the actual shoreline, and identify elevated features (i.e. dunes, elevated roadways, etc) that impede coastal inundation. The use of both topographic and bathymetric LiDAR has vastly increased the quality and accuracy of these coastal models by allowing coastal modelers to increase the resolutions of the model grids. The time required to produce the models has decreased as a result of less field work to identify and measure elevated features.

With most coastal terrain being generally flat, identification of elevated features can now be accomplished by the use of sun-illuminated DTMs. Using a network of cross-sections, elevated feature heights are easily quantified by examining the profiles for each cross-section. Additionally, the stability of the dune can be verified by volumetric calculations on the dune profile. For FIRM purposes, following the specifications presented by FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners Appendix D,* the volume of sand contained within a specific dune will determine whether or not the dune will be completely eroded or whether the sand will retreat.

Near shore bathymetry plays an essential role on the impact of storm surge heights. Gently sloping shorelines will see higher surge heights then those shorelines that are steep. Prior to bathymetric LiDAR, areas within the 18' bathymetric contour were estimated or crudely determined by shore-based leveling techniques. Now, full bottom coverage can be obtained easily and accurately, allowing coastal modelers to properly model the slope offshore. As with terrestrial portions of models, offshore features such as reefs can modify storm surge. Utilizing the same techniques as onshore, these offshore feature's heights can be accurately quantified.

COST OF LIDAR AND PHOTOGRAMMETRY

The cost of obtaining digital topography is going to depend on several factors including the accuracy of data required, method of capturing the data and most importantly the size of the area for which the data is being captured. The following graph shows a typical area-cost comparison of Photogrammetry and LiDAR for both 2ft-equivalent and 5-ft equivalent topographic data.



Photogrammetric and LiDAR contour cost per square mile (Maune, 2001)

As can be seen the cost of obtaining digital terrain data using photogrammetry is more cost effective for smaller drainage areas. LiDAR only becomes more cost effective for larger capture areas. It can also be seen that the difference between developing topographic data of higher quality using LiDAR is insignificant unlike photogrammetry where the cost is significantly higher for higher quality terrain data.

PROCURING AND EVALUATING A TOPOGRAPHIC DATA VENDOR

Procuring and evaluating a topographic data vendor is a critical time sensitive task. It is important that when flying for the data that the flights are performed during the winter months when vegetation is at a minimum allowing more ground points to be collected. Therefore it is critical that the data capture is done right first time otherwise it may be a whole years setback before the data can be effectively captured again.

Although the cost of acquiring digital terrain data has fallen significantly over recent years, the large geographic area associated with a municipality or region will inevitably result in a high cost. Therefore, it is often only financially feasible to obtain digital terrain data when cost sharing between organizations, departments or individuals occurs. Taking the example of a municipality, there are numerous departments that may utilize digital terrain data if available. For example, stormwater management departments will likely have a need for terrain data for floodplain modeling and mapping. Transportation departments may require terrain data for determining the profiles of roads and lines of sight, emergency management may require terrain data for emergency preparedness. It is also possible to collect additional data sets while flying for terrain, which can reduce the cost of putting aircraft in the air multiple times. This may include collecting digital imagery, which can be used by stormwater utilities to determine impervious areas or planners to determine land-use patterns.

Building a good selection committee to evaluate a vendor is the first step to a successful process. It is important to have the required standards in place before the contract is put out to bid to enable the vendor to understand exactly what is required and expected. A technology overview for all members of the selection committee is vital to ensure an adequate understanding of the technologies and required standards. If it is a first time selecting a vendor, it may be beneficial to request a remote sensing expert from a local university or a non-responding vendor to help during the evaluation process.

LITERATURE CITED

Wilkipedia, the free encyclopedia, Dec 2006 online URL: http://en.wikipedia.org/wiki/Photogrammetry

Maune, David F. 2001. *Digital Elevations Model Technologies and Applications: The DEM Users Manual*, American Society of Photogrammetry and Remote Sensing.

ACKNOLEGEMENTS

The following individuals contributed towards this document:

Hastie, Duncan, Project Manager, Dewberry

Kagy, Ken, Gwinnett County Stormwater Management

Maune, David, Ph.D. Dewberry

Puckett, Barry, GIS Manager, Gwinnett County

Slover, Kevin, Coastal/GIS Specialist, Dewberry