A Digital Elevation Model for Franklin, Wakulla, and Jefferson Counties Florida

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Introduction

Getting the above water (terrain) and below water (bathymetry) elevation right is critical to building a storm surge inundation model that accurately predicts inundation. The elevation dataset provides the foundation for the coastal inundation model and provides much of the guidance for building the finite element model that is used with hydrodynamic computer modeling software to estimate the extent of coastal storm surge related flooding. Marea Technology developed the elevation dataset or Digital Elevation Model (DEM) for the FEMA/Northwest Florida Water Management District (NWFWMD) Storm Surge Modeling effort in support of FEMA's flood map modernization program. The extents of the elevation model developed for this study are shown in Figure 1.

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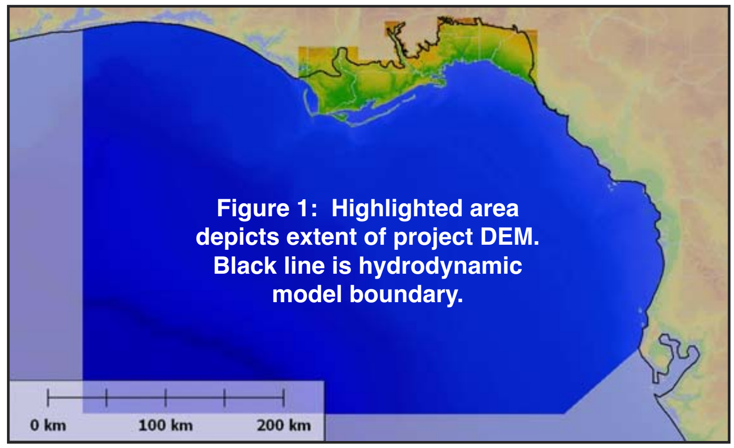

Figure 1: Highlighted area depicts extent of project DEM. Black line is hydrodynamic model boundary.

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LiDAR Provides Topographic Data

The DEM relies heavily on LiDAR remotely sensed elevation data. LiDAR, an acronym for Light Detection and Ranging, employs a scanning laser range finder, an accurate inertial navigation system, and GPS equipment onboard a light aircraft to collect elevation data over county-sized areas in a matter of days. Quoted accuracy for the data is better than 4 feet horizontally and 0.6 feet vertically (FDEM 2007). The high-density data (there's an elevation data point approximately every 4 feet) can provide an almost photographic representation of terrain. Of course, there are limitations. The laser range finder reflects off everything on the ground and attached to the ground. LiDAR suppliers have developed sophisticated routines to remove elevation returns from buildings, trees, overpasses, and bridges to produce a "bare earth" DEM. In areas of dense vegetation where most laser pulses reflect off leaves, there may be a limited number of true ground returns. As with any distributed measurement that is converted to a regular grid of values, it may not be obvious to the user that data in some areas are being approximated from data points that may be relatively far away. Normal topographic LiDAR gives inaccurate and unpredictable return values for water bodies. The supplier will normally classify these returns as water returns so that they are not included in the DEM. Regardless of the limitations, the ability to quickly acquire such accurate and dense elevation data has been revolutionary, especially in large-scale hydrodynamic modeling where entire counties are often included in the study area.

Hydrographic LiDAR can overcome the limitations of terrestrial LiDAR sensors, providing the water body bottom elevation to limited depths. Hydrographic LiDAR useful for large area DEMs is primarily available from two government sources: JALBTCX (Joint Airborne LiDAR Bathymetry Technical Center of Expertise), a consortium of numerous government agencies, and the USGS for data collected from the NASA EAARL system. These hydrographic systems use a different type of laser with very different employment and processing requirements than those for topographic systems. The hydrographic system is typically much more expensive to operate. Aside from the increased acquisition cost, data collection and data processing costs are much greater for hydrographic LiDAR. Grady Tuell, president of Optech International, a producer of both terrestrial and hydrographic LiDAR systems, described the reasons for the increased collection costs (Grady Tuell, email to the author, Feb 24, 2011):

"Typically, both types of lidars have a nominal 40 degree field of regard. However, bathymetric surveys are flown quite low: (400m) and topographic surveys are typically flown much higher (perhaps as high as 3000m). Consequently, the swath width of a typical topographic data collection is much wider than a bathymetric collection: (eg. 273m vs. 2052m). Based on this simple comparison, one could make an 'order of magnitude' statement that bathymetric lidar takes about 7 times more airtime to cover the same area."

However, one of the most limiting factors of hydrographic LiDAR is the need for reasonably good water clarity and calm seas. For these reasons, hydrographic LiDAR has primarily been limited to shoreline studies and is commonly employed to record elevation changes near the shoreline after significant storms.

Within our state, the Florida Division of Emergency Management (FDEM) has been instrumental in coordinating specifications, funding, and overseeing the collection of LiDAR for much of Florida's coastal areas. FDEM's coordination of over 15,000 square miles of LiDAR acquisition efforts by several government agencies has avoided duplication of effort while overseeing new data collection and cataloging the available data for Florida. The FDEM LiDAR website at http://www.floridadisaster.org/gis/LiDAR/index.htm provides an overview of available data and information on obtaining data.

Overall Model Construction

The elevation model constructed for this study is actually a collection of seven bathymetric datasets along with a LiDAR and non-LiDAR topographic dataset. The topographic datasets were built as typical gridded datasets while all bathymetric datasets were constructed as TINs (triangulated irregular networks). The gridded datasets were appropriate for the topographic data as the fixed resolution of the grids relates to the approximately fixed resolution of the source data. On the other hand, the variable resolution TIN format allows bathymetric datasets to have high resolution where high-resolution source data are available in bays and inland waterways and where the resolution is required to match the higher resolution of the finite element model in these same areas. Offshore the resolution expands to match the coarser resolution of the available source data and the relaxed requirements of the larger elements in the finite element mesh. An additional benefit of the TIN rather than grid format for the water areas is that it allows for simpler changes when bathymetric source data are updated from, for example, a newer survey.

The boundary of the TIN datasets is the imposed shoreline for the model. After a review of all available vector shorelines, none were found acceptable, so the shoreline for the elevation and finite element model was digitized using aerial photos and LiDAR data for guidance. The shoreline was set to zero elevation relative to the NAVD88 datum except in inland waterways where it follows bank elevation.

Topographic Model

The high quality of the topographic portion of the elevation model is primarily due to the high-quality LiDAR data available for most of the study area. Figure 2 shows the extent of LiDAR and non-LiDAR datasets that makeup the topographic portion of the DEM for the study area. Though coverage is now available throughout coastal Florida, at the time the DEM was constructed, there were areas within the study area where LiDAR was not yet available. In those areas the best available elevation data were from the USGS National Elevation Dataset (NED). The NED is a multi-source dataset that strives to use the best available data for each area.

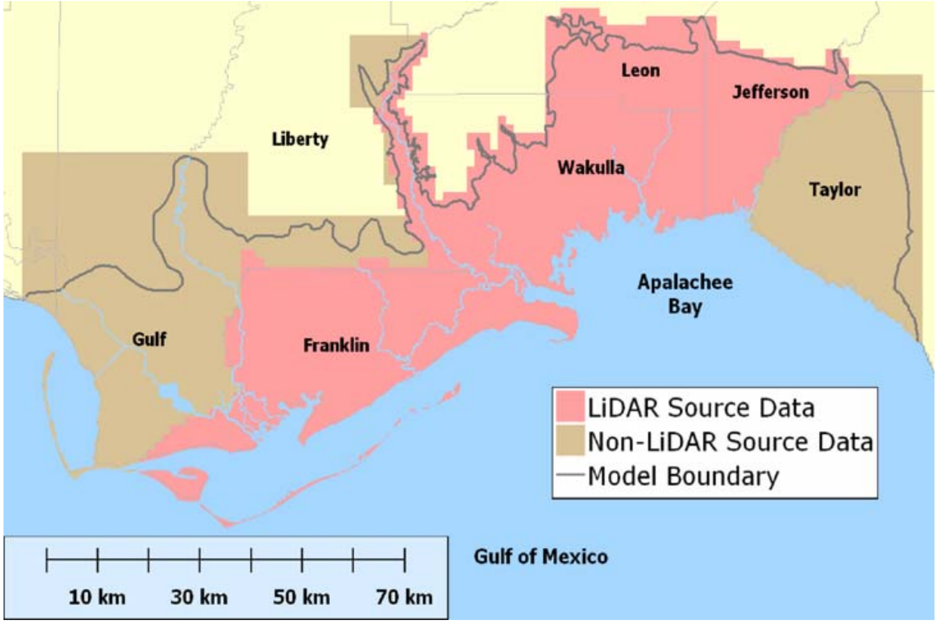

Figure 2: LiDAR and non-LiDAR source data for DEM. Grey line depicts hydrodynamic model boundary

In some areas, Taylor County to the east of the study area, for example, the NED data matched the LiDAR data quite well at the LiDAR /non-LiDAR interface. In other areas, most notably Gulf County, the match between NED data and LiDAR was poor. The interface area was most problematic at the western edge of the study area along the Apalachicola River at the Franklin and Gulf County border. In the area just east of the Apalachicola River where terrain elevation changes fairly rapidly, discrepancies of up to 3 meters between the NED and LiDAR data were not uncommon. The reason for the discrepancies was due to the sharp elevation drop occurring naturally through much of that area. The high-resolution LiDAR captures the change faithfully, but the low-resolution NED does not. Where the two datasets met, we were left with up to a 3-m discontinuity. If sharp step changes such as this occur in areas where

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the hydrodynamic model (finite element model) will have low resolution (nodes widely spaced), then the sharp change in the elevation model may be unimportant. However, in this case the sharp change was close to the Apalachicola banks and the necessary high-resolution, small, finite element model elements (50 to 100 meters). To improve the physical accuracy of the model, the interface was smoothed to make the LiDAR /non-LiDAR interface approximate the elevation change of nearby terrain.

It seems that though the source LiDAR has been subject to considerable scrutiny, one will still find missing and corrupted data in the available LiDAR datasets. For this study, five areas of missing or corrupt LiDAR data had to be replaced with a mixture of other available elevation data or constructed based on aerial photos and neighboring terrain. Careful examination is required to find all of the problem areas.

Vertical Feature Extraction

The ability to automatically extract vertical, raised, natural, and manmade features from LiDAR datasets is a new capability for coastal flooding models, which was used in this analysis. The resolution of floodplain area hydrodynamic models such as the one used for this study (node spacing for this mesh ranges from 30 to 300 meters) creates the possibility that features smaller than the local element size will not be described in the mesh. Such small features essentially disappear to the model because they lie inside the bounds of one model element. These "small" features need only be relatively small in one dimension for a triangular element to overlay the feature and have the elements' nodes register on surrounding lower terrain. These features may be very long in the orthogonal dimension. Consider a typical Interstate roadbed. At approximately 55 meters wide, most floodplain elements can overlay the roadbed and register on the surrounding terrain, possibly drainage ditches. The roadbed will likely be high enough above surrounding terrain and long enough to constitute a significant impediment to storm surge. Yet unless mesh elements are precisely placed with element edges lying along the road surface, the impediment will be missed and flow will propagate where it should not. While Interstate roadbeds may be easily identified by eye so that the mesh may be built to accurately represent their height, this is not the case for the majority of such long but narrow vertical terrain features. Most of these features are natural terrain features that are difficult to discern by observation but that may be located with the help of digital terrain processing. For this study, both natural and manmade, vertical, raised features were located and included in the hydrodynamic model through a digital processing procedure. Basics of the process are described in Coggin (2008). The process is parameter driven in that the procedure can be optimized for various objectives and local conditions. Ridges and valleys may be extracted.

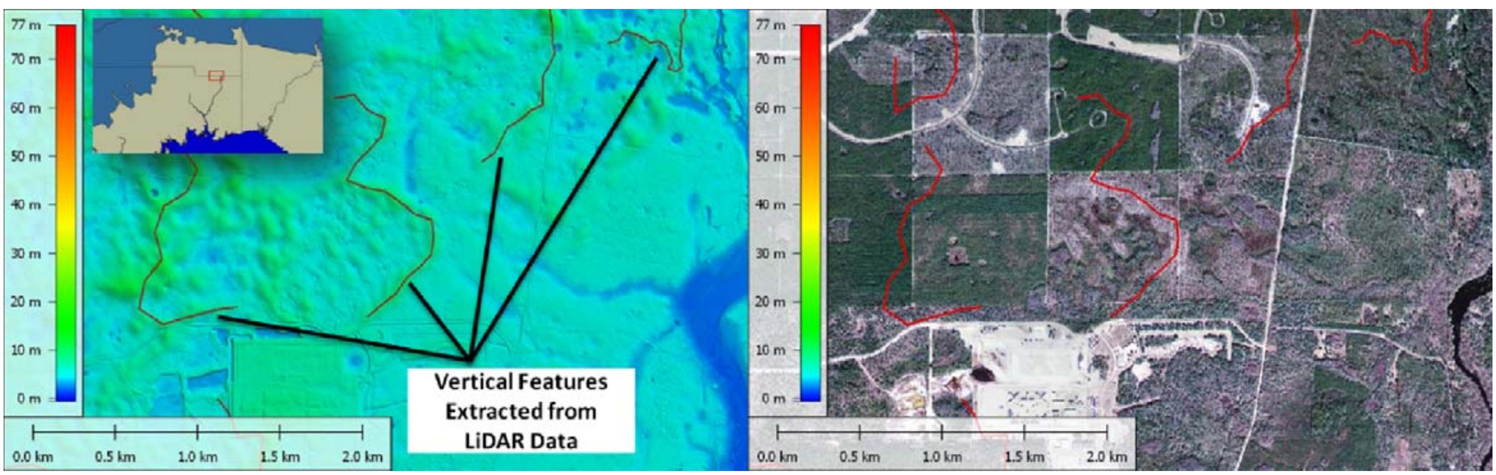

Figure 3: Artificially colored LiDAR data with automatically extracted vertical features (left). Extracted vertical features with aerial imagery (right).

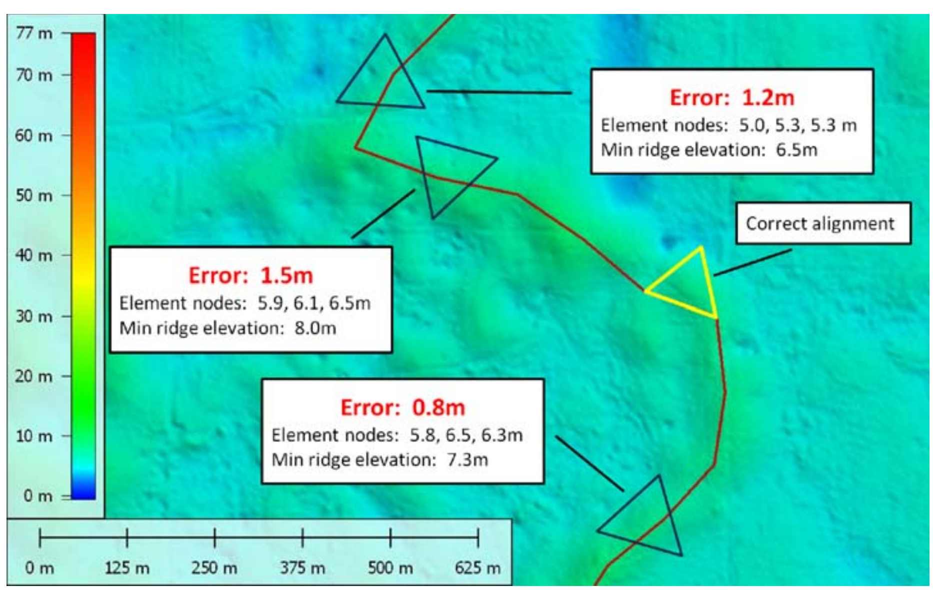

Figure 4: Expanded view of vertical feature from Figure 3. Red line is LiDAR-extracted vertical feature. Triangular elements are located to show errors if elements are not located properly to represent vertical features. Yellow element demonstrates the correct alignment possible if the vertical feature is located.

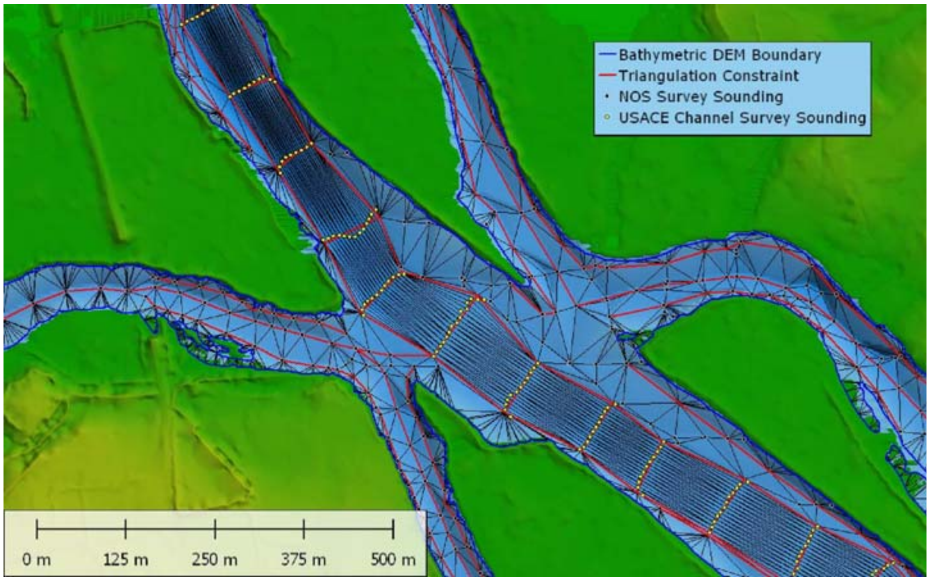

Figure 5: Bathymetric mesh developed from NOS soundings and a USACE channel survey. Red constraint lines are added to enforce proper channel cross-section.

Both are recognized by terrain form, or morphology; therefore, valleys are not dependent on traditional flow accumulation methods for delineation.

To demonstrate the benefits of such a procedure, we will review a small section of the floodplain terrain with the automatically acquired vertical features. An artificially colored section of LiDAR data containing a typical natural vertical feature is shown in Figure 3. The feature is taken from the floodplain area north of the Wakulla Correctional Institute near the Wakulla/Leon County border. The St. Marks River can be seen on the right side of the figure. Figure 4 is a close-up of the vertical feature in the center of Figure 3. The triangular elements shown match the typical local element size in this area of the mesh (128 m). Their worst-case orientation relative to the vertical feature (shown in Figure 4) allows the mesh elevation error to be estimated by not purposely aligning element edges along the vertical feature. For example, at the bottom location in Figure 4 the elevations at each mesh node are 5.8, 6.3, and 6.5 meters, while the minimum elevation of the section of the red line (vertical feature) within the element is 7.3 meters. For this positioning the element would begin to flow water when the water surface elevation reached approximately 6.5 meters. If the mesh were correctly positioned, it would not begin to flow water until the water level exceeded 7.3 meters. This results in an error of 0.8 meters due to failing to include the vertical feature. At the remaining two locations in Figure 4 the errors are greater, 1.2 and 1.5 meters.

For this study area, over 800 ridge and valley features in excess of 5000 feet in length were extracted from the LiDAR dataset and subsequently included in the finite element mesh. A separate article in this issue details the process to combine those features into a composite set of construction lines for mesh development.

Bathymetric Model

Construction of a bathymetric model for such a large area involves a large variety of data. For this project, some of the source data were from as distant as the 1800s and other data was collected as recently as the past year. In all cases the data were carefully prioritized to only include the most recent data for an area. The primary sources for offshore data consisted of digitally available National Ocean Service (NOS) hydrographic surveys and, where digital surveys were unavailable, NOAA nautical charts and even the very old "smooth sheets" of the originally recorded surveys. Apalachee Bay included a large area of over 150 square miles that was not covered by any digital surveys except widely spaced NOAA nautical chart data. It was for this large data void that the older surveys were also consulted. Fortunately, this lack of digitally available NOS surveys is unusual in Florida waters other than the areas of Apalachee Bay and Cedar Key. For inland waterways and bays, in addition to the NOS survey and NOAA nautical chart data, data were available from US Army Corp of Engineers (USACE) channel surveys, river cross-sections from one-dimensional models, and locally acquired data.

After determining data availability, the next step in bathymetric model construction was to convert depth soundings, which are referenced to a tidal datum, to reference the NAVD88 geodetic datum. This process has recently become faster and more accurate as NOAA has completed VDatum tidal to geodetic conversion grids for all of Florida's coastal waters. By employing the ADCIRC model, the same hydrodynamic model used for surge calculation in this study, NOAA has calculated the spatially variable conversion between geodetic and tidal datums. However, while there is fairly good coverage into bays, many inland waterways are still not covered by the VDatum grids. In these areas the DEM builder must revert to older methods of

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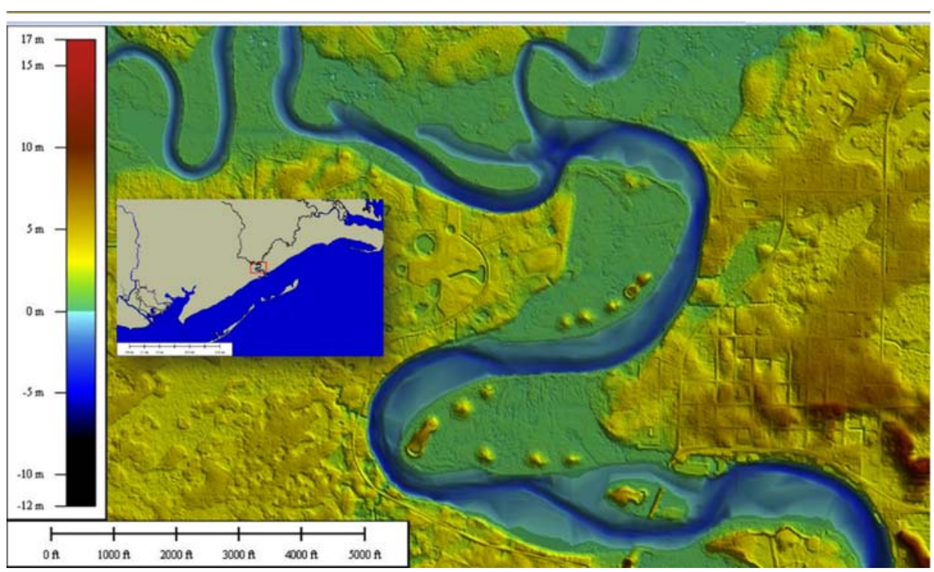

Figure 6: Composite Topographic / Bathymetric DEM near Carrabelle in Franklin County (red box in inset)

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conversion from tidal to geodetic datum by referencing data from NOAA tide gages.

Each individual dataset undergoes a quality control check before being combined into the larger model. Horizontal alignment errors for older datasets are corrected at this point, and then individual elevation outliers are deleted. The combination process joins the datasets with the newest datasets having the highest priority. Older datasets are "clipped" to the newer dataset boundaries when joining so overlap between datasets is prevented. After joining datasets, the growing DEM must be reviewed for systematic errors between source datasets. These errors between datasets are generally more problematic than the outliers just described as it is not uncommon to have adjoining datasets collected over 30 or more years apart.

When building the DEM for inland waterways, the modeling team must first determine parameters to limit the minimum size of rivers that will be modeled. For model accuracy and stability reasons, we generally wish to have at least three triangular mesh elements across a river. To limit computer simulation time for the model, we must limit the minimum element size. For this project we used a minimum nominal element size of 35 meters. These two parameters - minimum number of elements across a waterway and minimum element size - define the minimum waterway to model. We always find locations in the study area where we have to model some waterways that are below our target minimum size, and, for that reason, we apply a smaller minimum size when deciding which waterways will be included in the DEM. For this project, waterways down to 40-m wide were included in the DEM. Even that guidance gets overruled at times, most often when a narrow waterway must be modeled to include a wider area of interest upstream.

We can be sure that some of the smaller rivers in the floodplain will be covered with only low-density soundings or no soundings. While bridge scour reports may provide isolated depth values, in our work with NWFWMD their local expertise has been a valuable source of data. In current work with the NWFWMD, the District has acquired data for the project for some of these high interest inland waterways with their boat-mounted recording depth sounder. The data collected by the NWFWMD have partially overlaid recent surveys, providing an accurate calibration. While not suitable for navigation use, the provision of such data is a tremendous improvement over engineering estimation and is one of the valuable by-products of FEMA's Cooperating Technical Partner approach where the Flood Insurance Study (FIS) is overseen by a local government agency.

Converting river soundings or cross-sections to a proper three-dimensional DEM is one of the labor-intensive portions of the DEM construction. Construction generally follows from one of three initial conditions: (1) low-density soundings that must be augmented to construct a TIN, (2) high-density data that have sufficient soundings to support the soundings as TIN nodes, and (3) one-dimensional river cross-sections. In all three cases automation is the key ingredient to efficiently produce a high-quality DEM. A central requirement in all three cases is the ability to enforce a proper river cross-section along the length of the river. For our work we make use of Marea Technology's in-house developed tools to form a proper river cross-section from point data, channel surveys, and 1-D cross-sections. Figure 5 shows an example of a section of the bathymetric DEM constructed from a USACE channel survey in the center section of the river and NOS survey data in other areas. The red highlighted edges of the triangulation are constrained to force a proper cross-section. Figure 6 displays a portion of the combined DEM near Carrabelle in Franklin County.

Conclusion

The final DEM product must be accurate and must be constructed at an appropriate resolution to support the finite element mesh for the hydrodynamic model. It is important to understand that modeling decisions that affect the finite element hydrodynamic model also impact DEM construction. In fact, during the normal progress of a coastal storm surge analysis for an FIS, the impact on the DEM is felt earlier in the project cycle and requires the team to make early decisions concerning modeled area and resolution. The availability of LiDAR throughout most of Florida's coastal areas is the single most important factor in improving the accuracy of modern DEMs. The bathymetric portion of the DEM remains labor intensive, but investment in automation pays big dividends in efficiency and quality. A side benefit of a well-automated system is the ability to easily update the DEM as new data become available. With such a process the DEM gets a longer lease on life.

References

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- FDEM. (2007). "Baseline specifications for orthophotography and LiDAR V1.2" Florida Division of Emergency Management.

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