Region II Storm Surge Project - Coastal Terrain Processing Methodology

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This document was prepared by

A JV of Dewberry, URS, and ESP
RAMPP
Risk Assessment, Mapping, and Planning Partners

RAMPP
8401 Arlington Blvd.
Fairfax, VA 22031

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Acronyms and Abbreviations

ADCIRC	ADvanced CIRCulation Model for Oceanic, Coastal and Estuarine Waters
ALACE	Airborne LiDAR Assessment of Coastal Erosion
ASCII	American Standard Code for Information Interchange format
ASPRS	American Society of Photogrammetry and Remote Sensing
CAFRA	Coastal Area Facility Review Act
CHARTS	Compact Hydrographic Airborne Rapid Total Survey
cm	centimeters
CMAS	Circular Map Accuracy Standards
DEM	Digital Elevation Model
DTM	Digital Terrain Model
ENC	Electronic Navigational Chart
EROS	Earth Resources Observation and Science
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FGDB	File Geospatial Database
FGDC	Federal Geographic Data Committee
FIS	Flood Insurance Study
ft	feet
FVA	Fundamental Vertical Accuracy
GEODAS	GEOphysical DAta System
GIS	Geographic Information System
HYD93	Hydrographic surveys data exchange format
JALBTCX	Joint Airborne LiDAR Bathymetry Technical Center of Expertise
LiDAR	Light Detection and Ranging
LAS	American Society of Photogrammetry and Remote Sensing LiDAR data exchange format
LTEA	Localized Truncation Error Analysis
m	meter
MHW	Mean High Water
MLLW	Mean Lower Low Water
MLW	Mean Low Water
NAD83	North American Datum of 1983
NASA	National Aeronautics and Space Administration
NAVD88	North American Vertical Datum of 1988

NED	National Elevation Dataset
NGA	National Geospatial-Intelligence Agency
NMAS	National Map Accuracy Standards
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NSSDA	National Standard for Spatial Data Accuracy
NYC DOITT	New York City Department of Information Technology and Telecommunications
QA/QC	Quality Assurance/Quality Control
RAMPP	Risk Assessment, Mapping and Planning Partners
RMSE	Root Mean Square Error
SMS	Surface-water Modeling System
TIN	Triangulated Irregular Network
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VMAS	Vertical Map Accuracy Standards
WHAFIS	Wave Height Analysis for Flood Insurance Studies

SECTION ONE INTRODUCTION

The Federal Emergency Management Agency (FEMA) contracted Risk Assessment, Mapping, and Planning Partners (RAMPP), a joint venture of Dewberry, URS, and ESP, under the Risk MAP phase of the National Flood Insurance Program (NFIP) to provide comprehensive floodplain mapping, Geographic Information System (GIS), and hazard risk mitigation services. This report summarizes the identification and development of terrain data for storm surge modeling and coastal hazard analysis to support Flood Insurance Studies (FISs) in FEMA Region II. This effort was initiated in November 2009 and completed in June 2011.

1.1 PROJECT AREA

The coastal study encompassed all coastal counties in the State of New Jersey and the five Boroughs of New York City. In addition, the study team identified the need to extend the study area up the Hudson River to Troy, and into Nassau County, NY, and Fairfield County, CT. In total, the study required topographic data for 29 counties in part or whole. The specific counties are listed below and illustrated in Figure 1.

Whole County:

New Jersey:	Salem, Cumberland, Cape May, Atlantic, Burlington, Ocean, Monmouth, Middlesex, Union, Essex, Hudson, and Bergen
New York:	Richmond, Kings, Queens, Bronx, New York, and Westchester

Partial County:

Connecticut:	Fairfield
New York:	Nassau, Rockland, Orange, Putnam, Dutchess, Ulster, Columbia, Greene, Albany, and Rensselaer

Detailed bathymetric data were required for the regional study area. Best available data were acquired and integrated into a coverage that reached from Cape Henlopen, DE, to Narragansett Bay, RI. This extension of the coverage into the northeast ensured full detailed resolution of Long Island Sound and relevant hydraulic connections. The coverage includes all appurtenant estuaries and embayments, in addition to large rivers. The Hudson River was covered, up to the full extent of tidal influence at the Troy Dam.

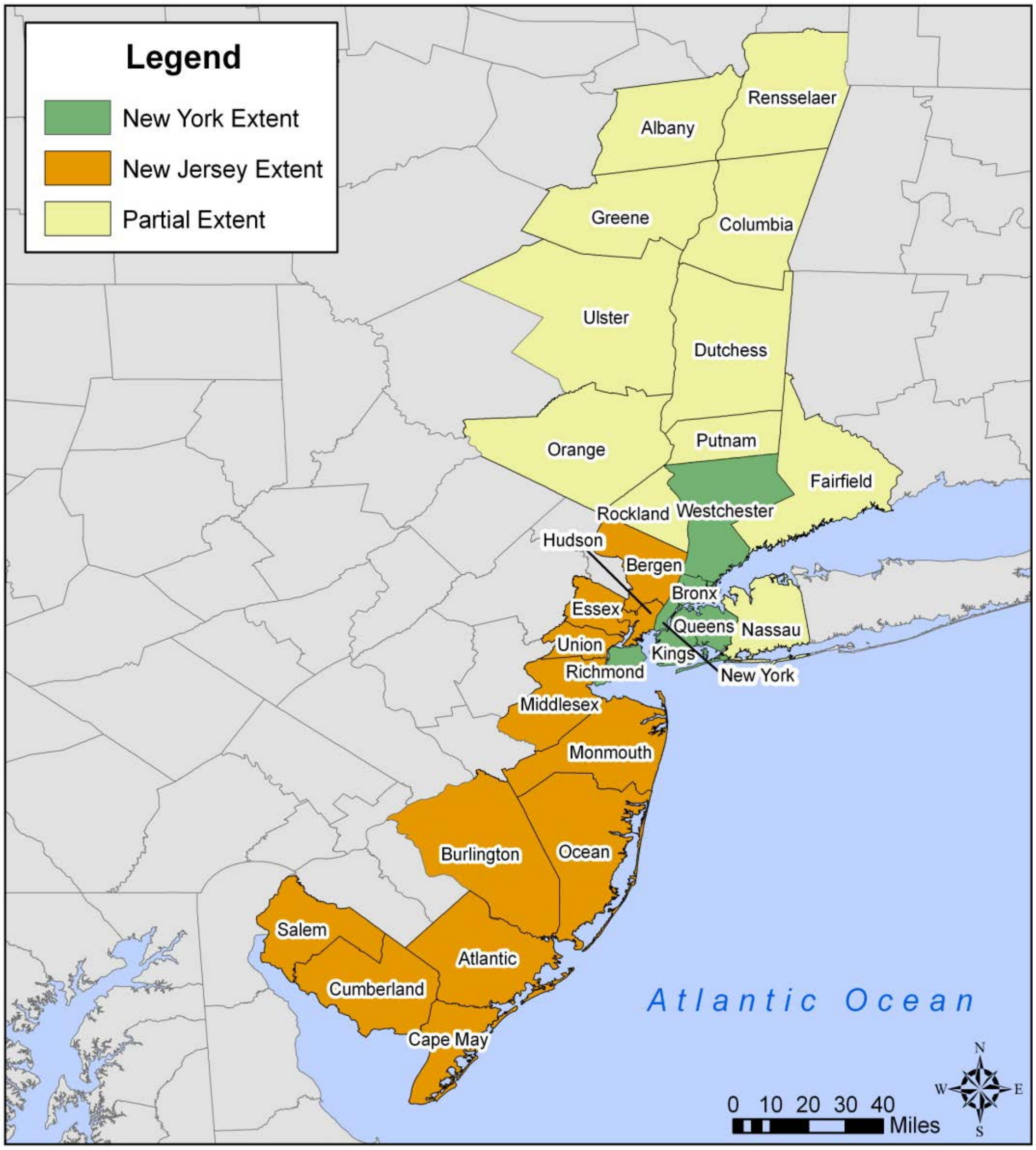

Figure 1. Overview of topographic needs in the study area.

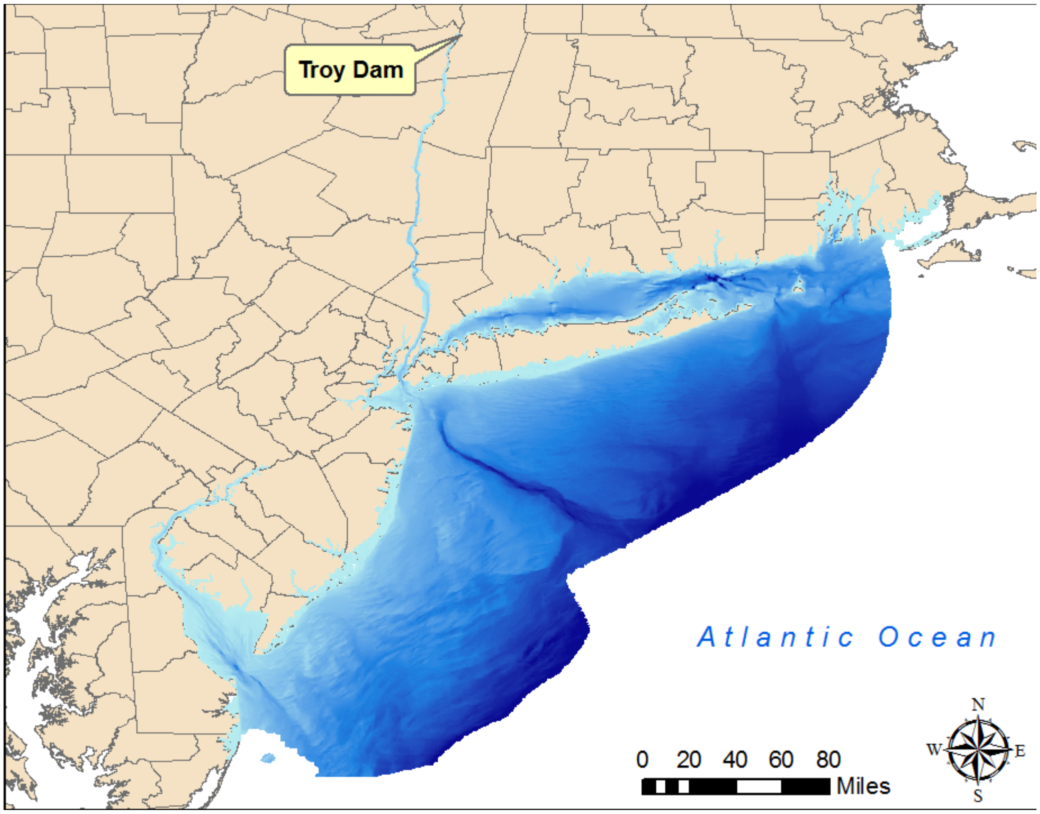

Figure 2. Spatial extent of required detailed bathymetric data.

1.2 PROJECT DATUMS AND UNITS

Data processed under this effort were converted to specified datums and units. These datums will be hereafter referred to as the project datum.

The Horizontal Coordinate System utilized is the North American Datum of 1983 (NAD83) New Jersey State Plane FIPS 2900, in feet. This coordinate system allowed for a planar reference with horizontal units in feet, consistent with the vertical units (as opposed to Universal Transverse Mercator), throughout the study area. Digital Elevation Models (DEMs) were converted to North American Vertical Datum of 1988 (NAVD88), in feet. The topographic datasets are specified in the appropriate datum for Flood Insurance Rate Map (FIRM) applications, where full resolution is required.

It should be noted that the ADvanced CIRCulation Model for Oceanic, Coastal and Estuarine Waters (ADCIRC) is specified in NAD83 geographic coordinates. ADCIRC requires metric units, with negative topographic elevations and positive depths. The final conversion of datums and units for ADCIRC was accomplished during mesh development. Additional re-projections were undertaken as needed for data use subsequent to the surge modeling effort.

The bathymetric data for the study area (Figure 2) was initially assembled and processed in the horizontal datum of NAD83 Universal Transverse Mercator (UTM) Zone 18N, and later converted to the project datum to facilitate seamless DEM generation. This differs from the topographic datasets because the full bathymetric dataset spans several State plane coordinate systems, and as a whole, is required only for ADCIRC. Further information on bathymetric data processing is detailed in Section 2.3.

1.3 APPROACH

The RAMPP study team prepared seamless topographic/bathymetric surface elevation models in support of storm surge modeling and coastal flood hazard analyses in the study area. The completed datasets served two purposes: 1) to provide base elevation data for the ADCIRC storm surge model; and 2) to provide base elevation data for FEMA overland wave analysis and coastal floodplain mapping (referred to hereafter as coastal floodplain analysis). Each of these goals has different requirements. For storm surge modeling, the ADCIRC model grid (also called a "mesh") developed for the study area has elevation nodes with a horizontal spacing ranging from 30 meters (100 ft) to more than 1000 meters (3280 ft). In contrast, the FEMA coastal floodplain analysis requires a much higher horizontal resolution, typically a horizontal cell size on the order of 3 meters (10 feet).

To best serve both the ADCIRC and coastal floodplain analysis applications, the typical process of first preparing data for the surge model, and then preparing the coastal overland wave hazard and floodplain analyses, was reversed. For this study, the DEMs were prepared at the resolution necessary for coastal floodplain analysis, and then resampled to a coarser resolution more suitable for surge analysis. This approach required data to be processed only once and made the overall effort more efficient. The process by which the data were treated involved six sequential steps, as shown in Figure 3. These steps are discussed in more detail in Section 2 of this document.

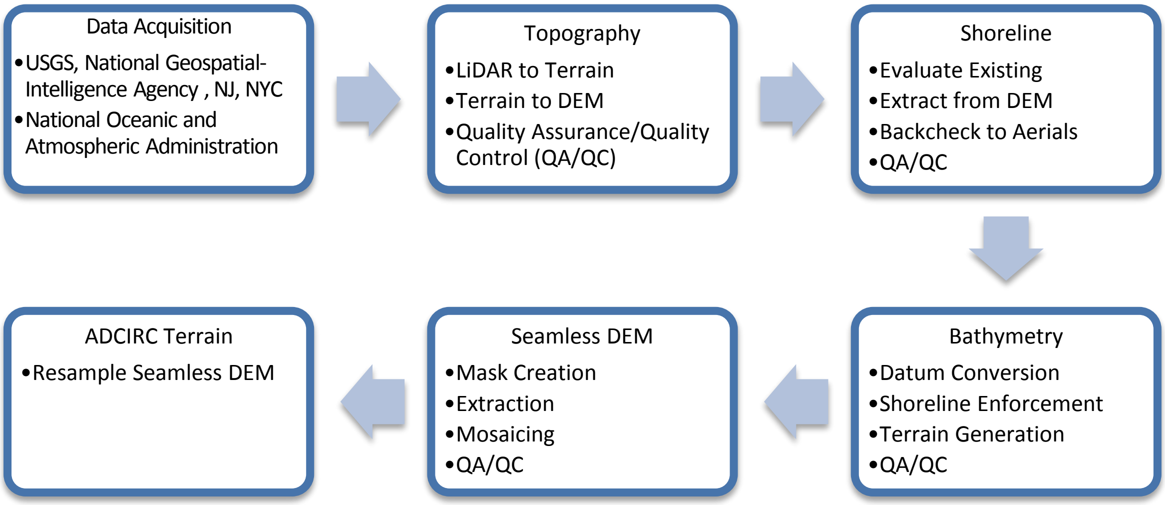

Figure 3. Overview of surface elevation generation process.

This effort was undertaken at the beginning at the storm surge modeling phase of the study and continued until the beginning of the floodplain mapping phase. Initially, it was not possible to secure topographic datasets for all counties that met or exceeded FEMA Floodplain Mapping

Standards. These datasets were acquired later in the study to support the overland wave analysis and floodplain mapping tasks. The existing data were acceptable for use in the surge modeling terrain due to the fact that the model grid is relatively coarse (at the smallest spacing approximately 100 ft versus 10 ft) and a representative surface is suitable for hydraulically sound model development. The FEMA *Guidelines and Specifications for Flood Hazard Mapping Partners* (April 2003) (G&S) recognize this and do not stipulate that these standards are applicable to storm surge model terrain data; therefore the effort proceeded with the best available data. Additional data collection was undertaken for several counties to improve data quality prior to the coastal floodplain analysis. As these datasets became available, they superseded the default data. Metadata and processing procedures for each dataset are explained in this report.

SECTION TWO DATA ACQUISITION AND PROCESSING

The goal of the data gathering effort was to obtain a topographic dataset for each county that met or exceeded standards for 2-foot mapping contours, as outlined in Appendix A: Guidance for Aerial Mapping and Surveying, FEMA's G&S and Procedure Memorandum No. 61 (PM 61). When the data did not meet these specifications, alternative best available datasets were used. Details of FEMA's horizontal and vertical accuracy standards for elevation data are provided in Appendix A of this report.

The size of the study area necessitated data acquisition from a variety of sources. Topographic and bathymetric data were collected from the following entities (specific sources are cited for each dataset in Appendix B):

Topography Sources:

U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, National Geospatial-Intelligence Agency (NGA), FEMA, and the New York City Department of Information Technology and Telecommunications (NYC DOITT).

Bathymetry Sources:

National Oceanic and Atmospheric Administration (NOAA), National Geophysical Data Center, NOAA Office of Coast Survey, U.S. Army Corps of Engineers (USACE) New York and Philadelphia Districts, and the New York State Department of Environmental Conservation (NYSDEC)..

2.1 TOPOGRAPHY

Topographic datasets were available in the form of Light Detection and Ranging (LiDAR) mass-points, tiled LiDAR-derived high resolution (1 m) DEMs, low-resolution (10 m) DEMs, and vector contour data. Each type of data was processed by a slightly different methodology as a result of associated technological constraints. All data were treated on a county-by-county basis; final topographic DEMs had a minimum and maximum cell size of 6.56 feet (2 m) and 32.8 feet (10 m), respectively. All data were provided with a vertical reference to NAVD88.

As previously mentioned, the FEMA G&S allow relaxed topography standards for storm surge model terrain data. This is due to FEMA's recognition that the models employed in the surge modeling effort are representative of larger areas and are therefore not as sensitive to detailed elevation representations as are the wave models and floodplain mapping. Subsequent detailed overland wave analysis and coastal floodplain mapping products are highly dependent on small changes in elevation, and as such, are held to a higher standard of input terrain data. New data were acquired and integrated into the effort in all cases where initial data sources did not fully meet FEMA standards for use in the coastal flood hazard analysis. These counties included:

- Albany County, NY
- Atlantic County, NJ
- Bronx County, NY
- Burlington County, NJ
- Columbia County, NY
- Dutchess County, NY
- Greene County, NY
- Kings County, NY
- New York County, NY
- Ocean County, NJ
- Orange County, NY
- Putnam County, NY
- Queens County, NY
- Rensselaer County, NY
- Richmond County, NY
- Rockland County, NY
- Ulster County, NY
- Westchester County, NY[1]

Treatment of LiDAR mass-point datasets: LiDAR data were provided as classified American Society of Photogrammetry and Remote Sensing (ASPRS) LiDAR data exchange format (LAS) files for Salem, Cumberland, Cape May, and Burlington Counties, NJ. Data were uploaded into Environmental Systems Research Institute, Inc. (ESRI) file geodatabases (FGDBs) as multi-point feature classes with elevation attributes based on Class 2 bare earth points. An ESRI Terrain dataset was generated and spatially constrained to the data extent for each county.

Terrain datasets are an efficient way to manage large amounts of point-based data in a geodatabase and produce high-quality, accurate surfaces. LiDAR, sonar, and elevation measurements can number from several hundred thousand to billions of points. Terrain datasets can be stored in file geospatial databases (FGDBs) and utilize point, polygon, and breakline feature classes to improve definition and representation of features. A feature unique to terrain datasets is the ability to either embed or reference source data. Each measurement is indexed, and a set of pyramids is generated. This allows GIS software applications to generate a multi-resolution Triangulated Irregular Network (TIN) surface, depending on the application. Digital Terrain Models (DTMs) can also be generated from the terrain dataset at a variety of resolutions.

An ESRI format raster dataset was then exported from the terrain at a resolution of 6.56 feet (2 m). This product became the base topographic DEM. All subsequent steps were consistent with treatment of other data types.

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[1] Hudson River shoreline only, data along Long Island Sound shoreline met standards.

Treatment of LiDAR-derived high resolution DEMs (1 m): LiDAR-derived DEMs for upper Monmouth, Middlesex, Union, Essex, Hudson, and Bergen Counties, NJ, were provided at a 1-m resolution in a tiled raster format. Because of technological constraints, it was not possible or desirable to produce continuous coverage for each county at this resolution. To facilitate seamless countywide coverage, each tile was converted to points and loaded into an ESRI FGDB for the countywide extent. An ESRI-format raster dataset was then exported from the terrain at a resolution of 6.56 feet (2 m). This product became the base topographic DEM. All subsequent steps were consistent with treatment of other data types.

Treatment of vector contour data: Elevation data were available as vector contours with elevation attributes for Burlington and lower Monmouth Counties, NJ, in addition to Kings, Queens, Bronx, New York, Richmond, and Westchester Counties, NY. These data were first uploaded into ESRI FGDBs as a polyline feature, and then an ESRI Terrain dataset was generated. In the case of Burlington County, a TIN was provided in the data deliverable. This was used in lieu of creating an ESRI Terrain. An ESRI format raster dataset was then exported from the terrain (TIN in the case of Burlington) at a resolution of 6.56 feet (2 m). The DEM product became the base topographic DEM. All subsequent steps were consistent with treatment of other data types.

Treatment of low resolution DEMs: For the storm surge modeling effort, data for Atlantic and Ocean Counties, NJ, and all partial coverage counties (with exception of Nassau County, NY) were sourced from the USGS National Elevation Dataset. These data were projected to the project datum, and vertical units were converted from meters to feet using a factor of 3.2808. This product became the base topographic DEM. All subsequent steps were consistent with treatment of other data types.

Topographic Terrain: Development of the topographic terrain involved the following steps:

1. Identification and acquisition of the best available data for each county in the study area with coastal flooding exposure;
2. Preparatory editing and application of the appropriate corrections to the data if problems were apparent. This includes removing spurious data points, correcting false elevations over water bodies (such as ponds, lakes, rivers, bays, oceans), addressing voids, and removing topographic elevations seaward of the shoreline;
3. Generation of the ESRI Terrain feature (where deemed necessary);
4. Generation of base topographic DEMs;
5. Application of a horizontal datum conversion, where necessary, to bring the data into the project datum;
6. Execution of independent quality control (QC) of the data, including identification, documentation, and disclosure of identified problems;
7. Resolution of comments;
8. Submission for Quality Assurance (QA)/QC backcheck;
9. Extraction to coastal study extent (shoreline to identified upper limit); and
10. Creation of Federal Geographic Data Committee (FGDC)-compliant metadata.

2.2 SHORELINE

The shoreline demarks the boundary where water and land meet, and shoreline definitions vary depending on application. For example, coastal zone management and shoreline change analysis typically use a definition of mean high water (MHW). In coastal FISs, the Wave Height Analysis for Flood Insurance Studies (WHAFIS) model utilizes a shoreline reference of zero NAVD88 to define the landward limit of topography and seaward limit of bathymetry. As such, the shoreline vector was defined as the zero NAVD88 contour line, extracted from the topographic data for each county and edited as needed. This feature serves four purposes for the Region II coastal FIS restudy:

1) facilitate a clean transition from the bathymetric to topographic dataset in the seamless DEM,

2) provide a boundary and guiding arc for ADCIRC mesh generation,

3) provide an accurate reference location for the zero elevation contour for the WHAFIS software, and

4) provide accurate cartographic representation of the shoreline on the final cartographic product, a FEMA FIRM scaled at 1"=500'.

Existing shoreline data are often dated and poorly represent present-day conditions (Figures 4 and 5, for example). Also, existing data are typically referenced to different tide datums (typically MHW) and are therefore difficult to use in seamless terrain applications and FIS applications. Thus, use of “as-is” shoreline data for enforcement of the shoreline vector in construction of seamless terrain products can result in erroneous land form representation and false depths and/or elevations.

To overcome these issues and accurately represent the current coastal condition, the study team extracted the zero contour from each topographic DEM. The vector line was then put through a QC process that checked for potential artifacts and ensured that the location matched the most recent aerial photographs. Figure 4 and Figure 5 show examples of both the existing (NOAA-sourced) and derived shorelines compared to the most recent aerial photographs available at the time of analysis. Aerial photography employed for this was typically sourced from the FIRM base map for each county.

Ideally, the shoreline is extracted from the topography at an elevation of 0 feet NAVD88. Unfortunately, it is difficult to obtain a continuous feature at this elevation. This is because of limitations in the collection process for the topographic LiDAR, as the light spectrum used for the laser reflects off the water surface. The lowest extent of the topographic coverage therefore depends on the timing of the LiDAR acquisition with tidal fluctuations. If LiDAR acquisition is not coordinated with tidal fluctuations, topographic coverage is limited to elevations above the water level at the time of collection.

In cases where a continuous vector could not be derived at a zero NAVD88 elevation, the proxy was the lowest elevation contour that was reasonably continuous on the order of one to several miles long. All segments of the extracted shoreline retained the source elevation attribute. Where a shoreline could not be extracted from the topography at an elevation below the MHW, an existing cartographic representation (NOAA or State agency) was used as a proxy. In these instances, the cartographic representation was corrected to reflect present-day conditions, if necessary, and assigned an appropriate representative elevation to facilitate hard-line representation in the DTM.

In areas where the coast was hardened, such as with revetments, seawalls, or in ports and harbors, it was necessary that the shoreline features represent the edge of the engineered shoreline. Coastal structures that may influence flow, such as jetties, were included as part of the shoreline. Elevated coastal structures, such as such as fishing piers, were not included as part of the shoreline.

Digitizing shoreline data involved the following steps:

1. Extract the shoreline from the most recent, best available topography;
2. Review and hand-edit as necessary to remove erroneous or non-representative data;
3. Supplement extracted shoreline with NOAA, State, or other data as necessary;
4. Visually QA/QC feature and hand-edit as necessary to be consistent with project aerials; and
5. Create FGDC-compliant metadata.

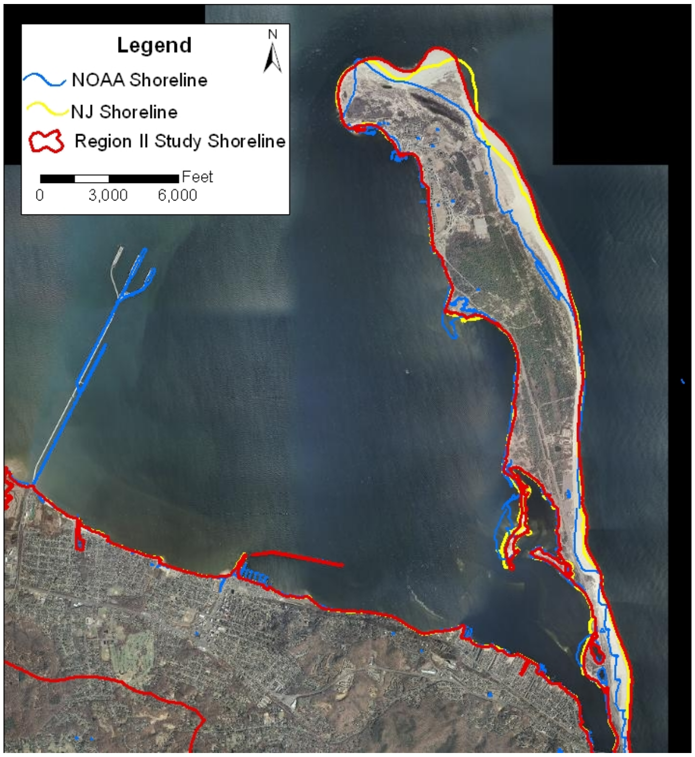

Figure 4. Extracted (red), best-available NOAA shoreline (blue - 1974), and NJ State shoreline (yellow - 2002) compared to 2008 aerial photograph at Sandy Hook, NJ.

Figure 5. Extracted (red), NOAA shoreline (blue - 1974), and NJ State shoreline (yellow - 2002) compared to 2008 aerial photograph at Great Egg Harbor Inlet, NJ.

2.3 BATHYMETRY

This section discusses the approach and procedures RAMPP implemented to produce a detailed bathymetric surface in support of storm surge and coastal flood hazard modeling efforts for FEMA Region II. The completed bathymetric surface served two purposes: 1) provide base depths for the ADCIRC storm surge model for ocean and inland water features, and 2) provide base depths for FEMA overland wave analysis.

Bathymetric data are available from a wide variety of sources. Data from the various sources were compiled into a single ESRI Terrain dataset. The ESRI Terrain dataset facilitated one-time assembly and editing of the disparate datasets needed for this application. Once the terrain features were complete, they directly supported generation of a coarse resolution DEM for the ADCIRC model and a higher resolution DEM for the overland wave analysis.

The following data were evaluated for incorporation into the final bathymetric DTM:

1. NOAA Hydrographic Surveys and Electronic Navigational Chart (ENC) Data
2. 2005 USACE Topographic and Bathymetric LiDAR
3. 2000 Airborne LiDAR Assessment of Coastal Erosion
4. USACE, New York District, Bathymetric Surveys
5. USACE, Philadelphia District, Bathymetric Surveys

6. NYSDEC Hudson River Estuary Bathymetry Grid

NOAA Hydrographic Surveys and ENC Data: GEOphysical DAta System (GEODAS) is an interactive database management system developed by the National Geographic Data Center for use in the assimilation, storage, and retrieval of geophysical data. GEODAS software manages several types of data, including marine trackline geophysical data, hydrographic survey data, and gridded bathymetry/topography (http://www.ngdc.noaa.gov/mgg/geodas/geodas.html).

Survey data were downloaded from GEODAS in the Hydrographic Survey’s Data exchange format (HYD93). The data were in an American Standard Code for Information Interchange (ASCII) format tab-delimited file with the hydrographic survey identification, latitude, longitude, depth, depth type, and cartographic code. Metadata regarding the vertical datum and units were provided with the data in a separate file. In geographical areas where no hydrographic survey data were found, it was necessary to supplement with charted soundings. However, data from the charts were often so antiquated that digital copies of the data did not exist. Therefore, ENCs were downloaded from NOAA and converted to an ESRI shapefile format. ENCs are exact replicas of the paper charts that have been converted to digital format.

2005 USACE Topographic and Bathymetric LiDAR: The LiDAR-derived data were collected by the Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX) using the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system. The hydrographic and topographic data were collected to depict the elevations above and below the water along the immediate coastal zone. The survey generally extends 750 meters inland and up to 1,500 meters over the water (depending on local water depth and clarity).

After careful review of the 2005 CHARTS data, it was determined that it would not be beneficial to add the data to the final bathymetric dataset. Incorporation of these data offered little benefit because of the lack of consistent coverage along the shoreline and large data gaps. As evident in Figures 6 and 7, the CHARTS data show very limited bathymetric coverage and large areas of no data. It is likely that there was limited water clarify at the time of the CHARTS flights, which limits that laser-based system’s ability to penetrate the water column and provide bathymetry elevation returns.

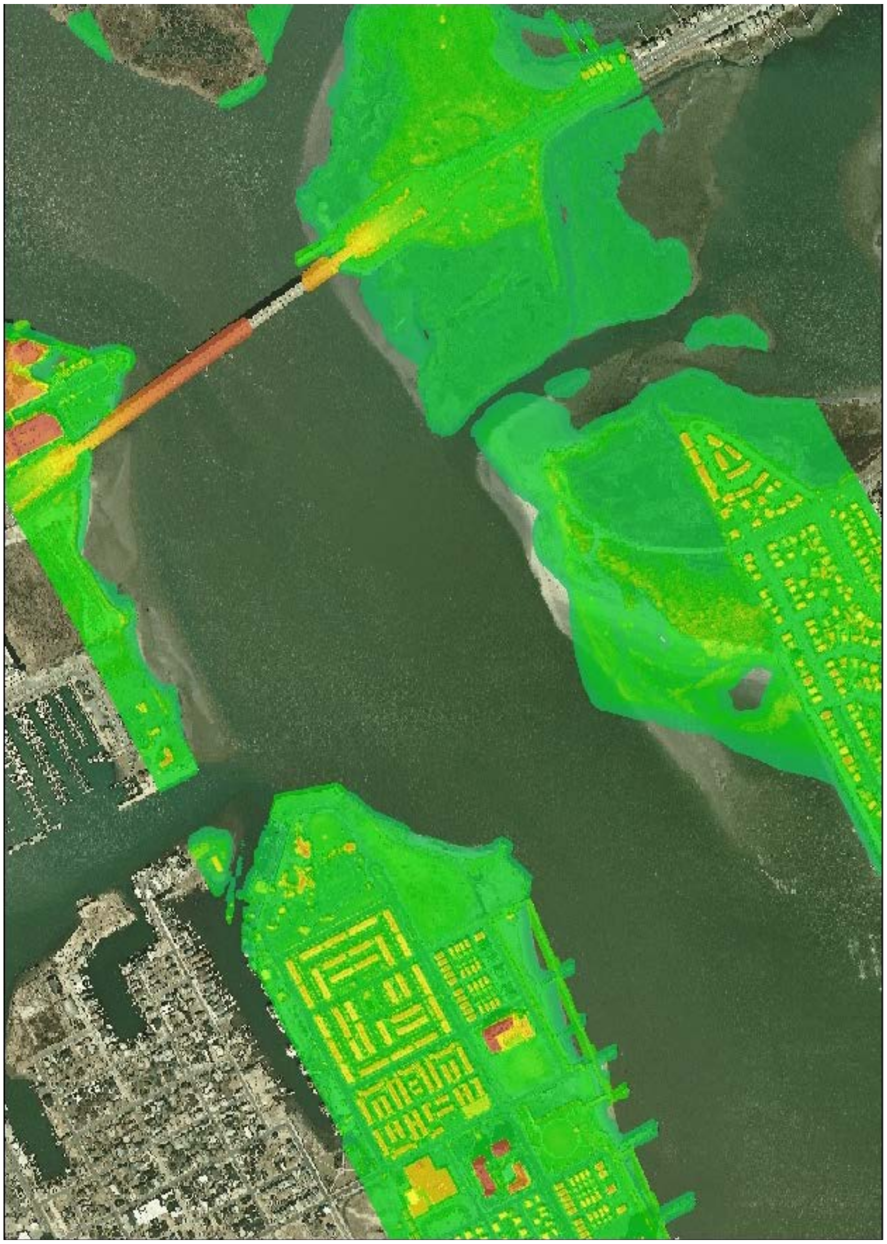

Figure 6. 2005 USACE Topographic and Bathymetric LiDAR data overlaid on a 2007 aerial photograph. The area shown is in the vicinity of Atlantic City, NJ, and demonstrates the lack of bathymetric coverage in the dataset.

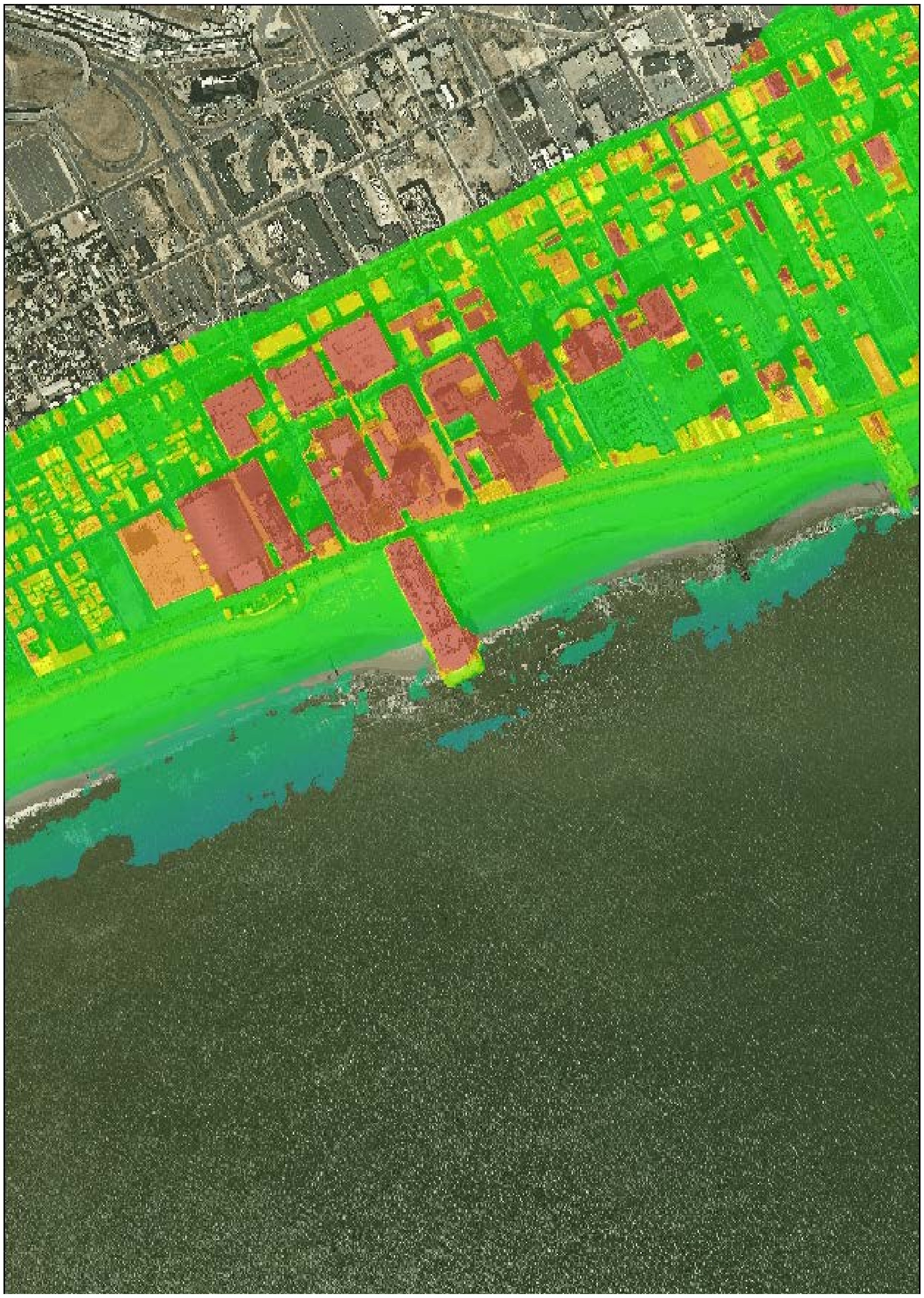

Figure 7. 2005 USACE Topographic and Bathymetric LiDAR data overlaid on a 2007 aerial photograph. Bathymetric coverage is limited to small patches in the near shore. The image demonstrates the lack of coverage, which is typical along the entire coastline in the 2005 CHARTS dataset.

2000 Airborne LiDAR Assessment of Coastal Erosion (ALACE) Project: The ALACE project was a partnership between NOAA, the National Aeronautics and Space Administration (NASA), and USGS. It has been collecting baseline coastal topographic data for the coterminous United States since 1996. NOAA left the partnership after the fall 2000 season, but USGS and NASA continue to collect data for research. The ALACE collections are typically targeted at a narrow strip of beach and usually a kilometer or less in width. Many areas have both baseline data and post-storm data. In general, these data have not been checked with ground control, but have undergone internal consistency checks.

The acquisition of baseline coastal topographic data primarily occurs during the fall, when the beach is at its widest as a result of sand accumulation over the summer months. However, research missions are also conducted at other times to study the coastal impacts of weather phenomena such as El Niño or hurricanes. All flights are timed to occur within a few hours of low tide, when the beach is most exposed.

After reviewing the information and visually observing the data in a GIS environment, it was determined that the 2000 LiDAR mission would not be used in the final bathymetric dataset, because of the lack of any bathymetric coverage (Figure 8). The topographic aspect of the datasets was also not desirable because of the data's age and incomplete coverage, which was limited to the immediate vicinity of the coast.

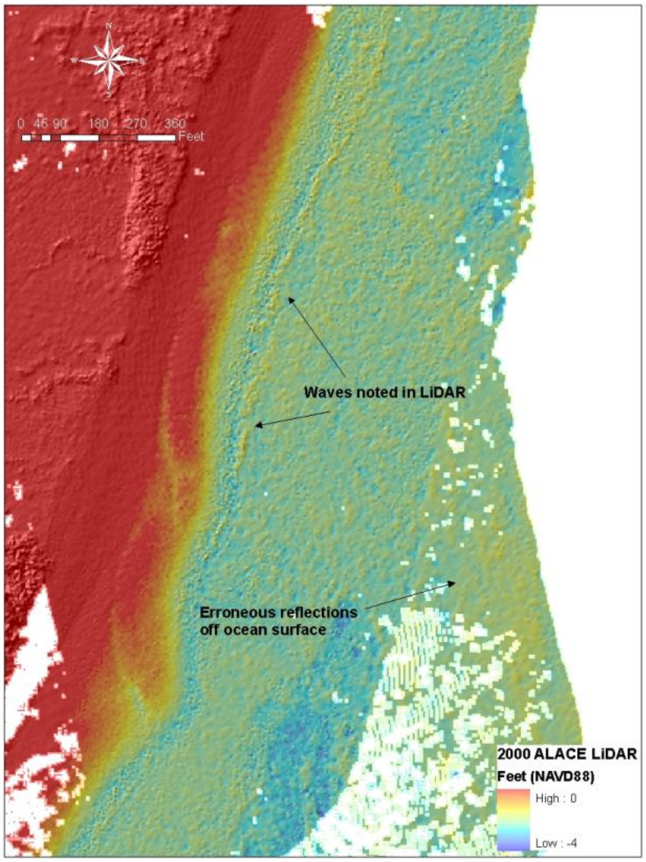

Figure 8. Example of issues noted in ALACE data.

USACE Bathymetric Surveys: The USACE is responsible for reporting the conditions of federally maintained navigation channels. Each USACE District performs periodic surveys throughout its geographic area of responsibility to determine channel conditions. For datasets provided by the Philadelphia and New York District offices, each survey was converted from its original format into an ESRI point shapefile. Next, each survey was visually assessed to determine if inclusion into the final bathymetric FGDB would enhance the final product. Most surveys consisted of such isolated areas that they would not significantly benefit the final product.

USACE New York District: A total of 68 surveys from the New York District were reviewed. Of these, the study team used only one in the final FGDB. The other 67 surveys were not used due to the lack of coverage, isolated survey extent, sporadic soundings, large gaps between surveyed transects, or because they were superseded by newer surveys (such as NOAA shallow water multi-beam surveys). Some examples of the data are shown in Figure 9 and Figure 10.

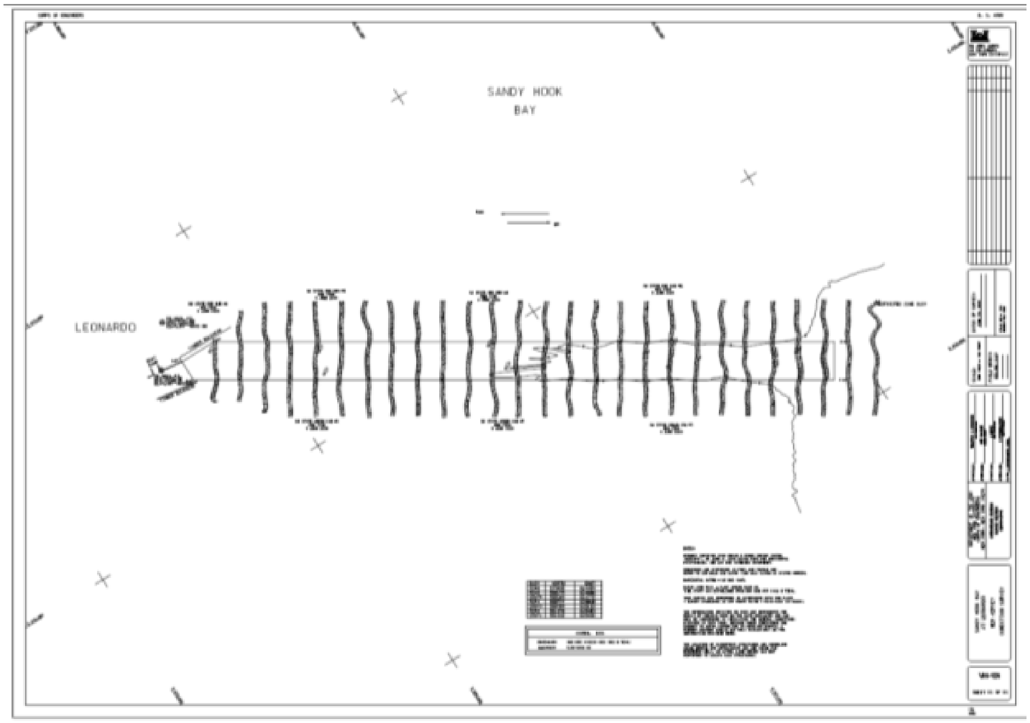

Figure 9. NY District USACE bathymetric survey at Sandy Hook Bay at Leonardo, NJ. This is one example of the many "isolated" surveys not used.

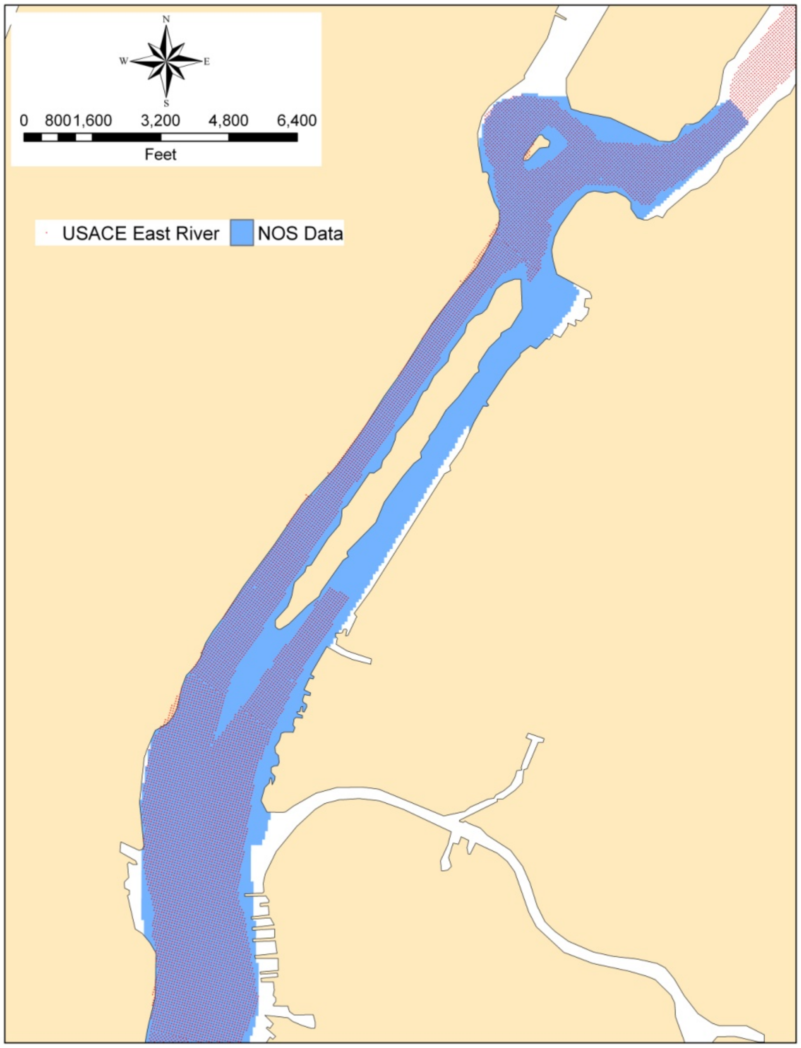

Figure 10. Example of USACE survey (red) coverage in East River, NY, that was superseded by NOAA hydrographic survey data with more continuous coverage (blue).

USACE Philadelphia District: RAMPP acquired and reviewed a total of 93 surveys from the Philadelphia District. Of these, only four were added to the final bathymetric FGDB. Although the data included several surveys in the Intracoastal Waterway, those areas were already adequately covered by NOAA National Ocean Service (NOS) hydrographic survey data. A comparison of the depths shows only a 1- to 2-foot discrepancy between the NOS and USACE data. As these channels are subject to continual shoaling and periodic dredging, the study team determined that the NOS data provided adequate representation for the purposes of this application.

NYSDEC Hudson River Estuary Bathymetry Grid: RAMPP retrieved the Hudson River Estuary Bathymetry Grid from the New York State GIS Clearinghouse. The grid provided bathymetric coverage from the Verrazano Narrows to Troy, NY. The dataset is composed of multiple surveys ranging from 1930 to 2003 and provides depths from a 1998-2003 multi-beam survey of the Hudson River in areas deeper than 4 meters. Comparison to the available NOAA data holdings indicated that the grid provided the best available data from the southern Dutchess County, NY border north to the Troy dam. Depths were already relative to NAVD88 and no further conversion was needed. The raster dataset was processed into an ESRI multi-point feature class then added to the project database for incorporation into the bathymetric DTM.

Data Processing: Once all datasets were in hand, the next step was to process the XYZ points to a DTM. The first step was to convert all soundings to the NAVD88 project datum. The GEODAS and ENC datasets were downloaded in their native vertical datum: either Mean Lower Low Water (MLLW) or Mean Low Water (MLW). The data were split into two separate files (MLLW or MLW) and converted to NAVD88 using the NOAA National Geodetic Survey VDatum software. The resulting transformation factors for the study area are shown in Figure 11 and Figure 12.

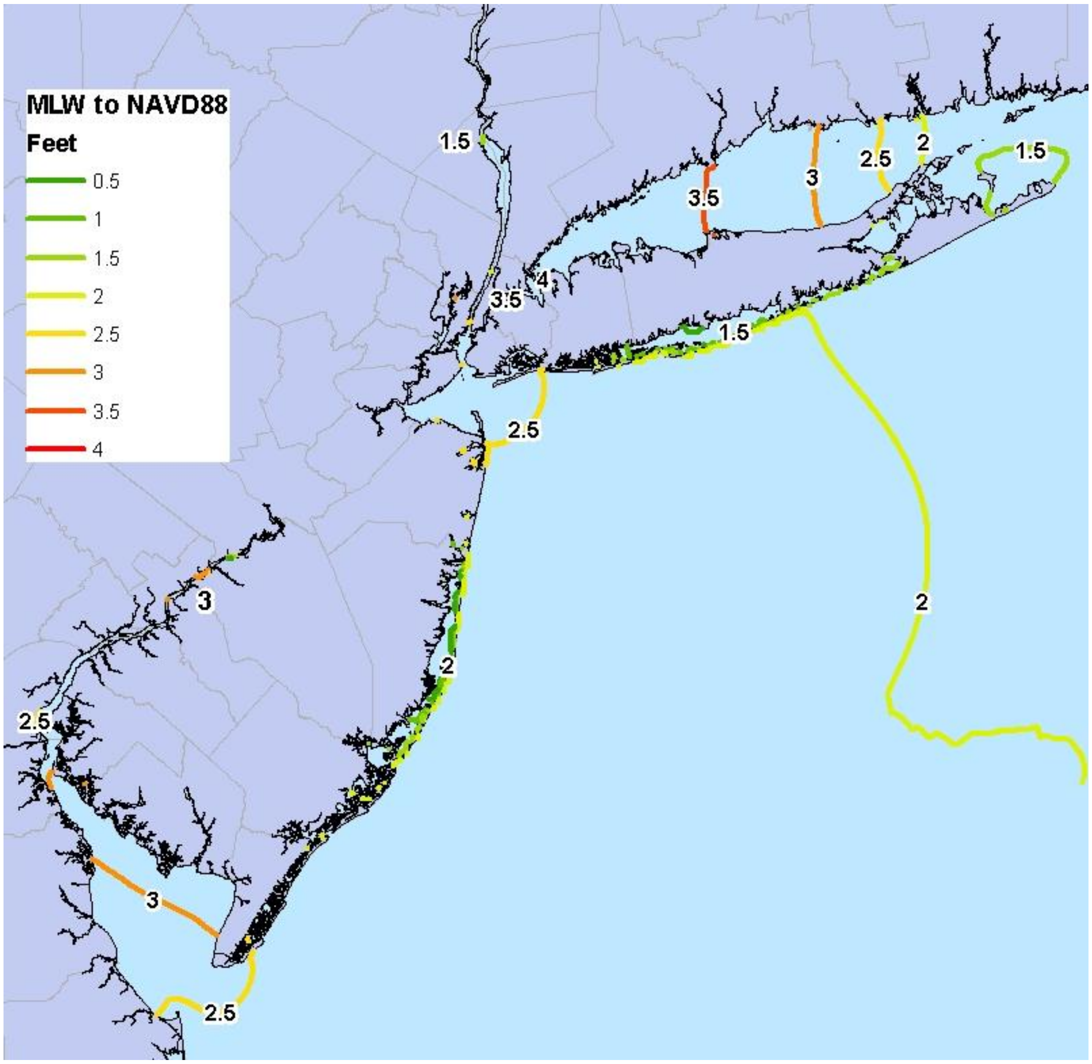

Figure 11. Conversion factor of bathymetric data from MLW to NAVD88. Transformation factors are added to the depth (i.e., -9.0 MLW feet + [+2.5 feet] yields a depth of -11.5 feet NAVD88).

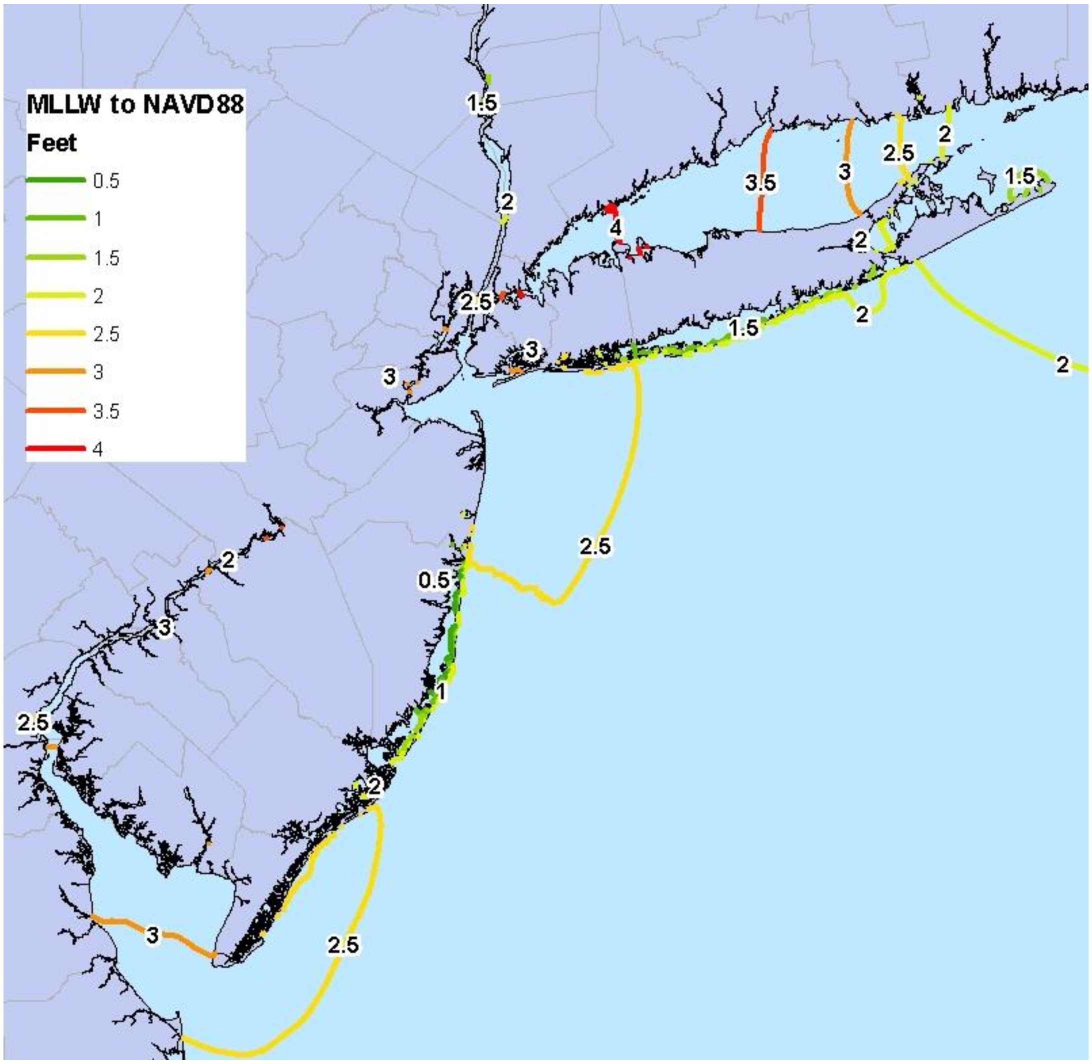

Figure 12. Conversion factor of bathymetric data from MLLW to NAVD88.

After establishing a common vertical datum, all files were imported into ArcInfo for visual inspection. Priority was given to USACE data, meaning in areas where USACE data overlapped the NOAA data, the NOAA data were removed from the final dataset. Additionally, the GEODAS data contained many overlapping surveys. The study team inspected both the age and coverage of these overlapping areas on a case-by-case basis to determine which should be retained.

Bathymetric Terrain: Development of the bathymetric terrain involved the following steps:

1. Identification and acquisition of the best available data for the study area from multiple sources;
2. Completion of appropriate preparatory editing. Application of the appropriate corrections to the data if problems were apparent. This included removing spurious data points and false elevations, filling in voids, and removing data points landward of the shoreline;

3. Translation of disparate vertical datums to the project datum;
4. Projection of data to common horizontal datum. *Note: Because of the large extent of bathymetric data, the team used UTM Zone 18N as the common horizontal datum. Bathymetric data were converted to the project datum prior to creation of the seamless DEM for each county*;
5. Import of data to ESRI FGDB;
6. Generation of ESRI Terrain features, with the shoreline enforced as a hard-line elevation and the hydrographic soundings as mass points;
7. Export of the ESRI Terrain to ESRI raster;
8. Clipping of each raster to over-water areas;
9. Execution of independent QC of the data, including documentation and disclosure of identified problems;
10. Resolution of comments;
11. Submission of revised dataset for QA/QC backcheck; and
12. Creation of FGDC-compliant metadata.

SECTION THREE FINAL DATA DEVELOPMENT

3.1 SEAMLESS DEM DEVELOPMENT

The final step in the terrain processing task was to process the discrete topographic and bathymetric DEMs into continuous (seamless) DEMs for both land and water-surface elevations. Utilizing the previously developed shoreline files (discussed in Section 2.2), a clean transition can be made from the bathymetric to topographic dataset in developing the seamless DEM. The shoreline serves as both the landward boundary of the bathymetry and the seaward boundary of the topography, allowing a common continuous feature to facilitate interpolation between the two disparate datasets.

The RAMPP study team approached seamless DEM generation on a county-by-county basis. To facilitate this process, a mask was created for each county's topographic and bathymetric datasets in order to define the spatial boundaries of the datasets. The topographic mask extended from the shoreline boundary to the identified upper limit (in this case, +25 feet NAVD88, with a 2,000-foot horizontal buffer applied). In a similar fashion, the bathymetric mask extended from the shoreline boundary to the pre-identified lower depth limit (-60 feet NAVD88[2]), or alternatively the limit of the bathymetric dataset.

As described in the previous section, the shoreline data were then inserted into the bathymetric dataset as the upper boundary, and a hard-line feature was attributed with its source elevation. An ESRI Terrain was generated that incorporated both the points (soundings) and the hard line (shoreline). This step ensured a common elevation between the bathymetric and topographic datasets at the shoreline boundary. The topographic dataset was then extracted to the topographic mask, and the two sections (topography and bathymetry) were merged by raster mosaicking. Any remaining gaps between the two sections were then filled by an algorithm that identifies voids within the dataset and fills them with a nearest-neighbor interpolation. Visual examples of this process are shown in Figures 13 through 16.

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[2] Limited bathymetric data (up to 1.5 times the breaking wave height) is required for coastal floodplain analysis. These data were subsampled from the final bathymetric dataset.

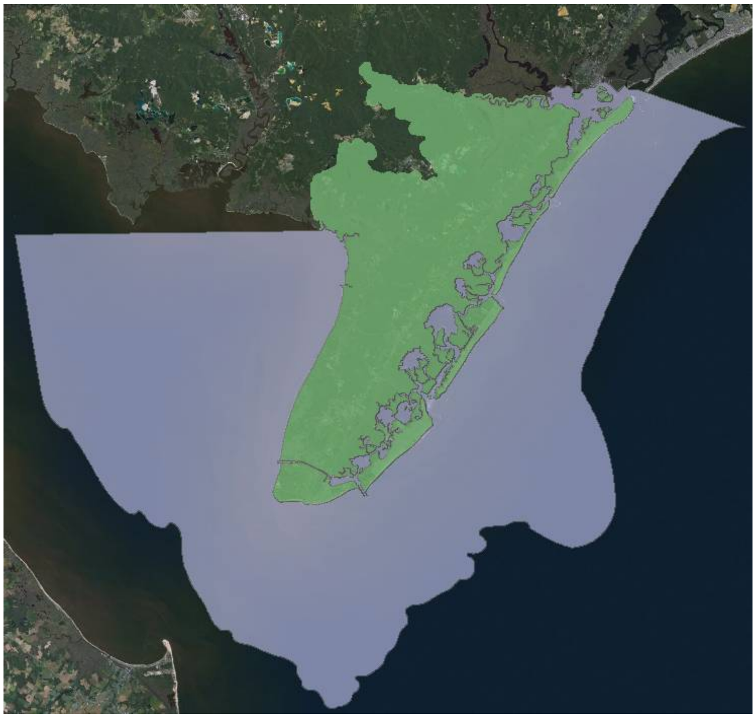

Figure 13. Example of topographic and bathymetric masks for Cape May County. The shoreline served as the common boundary.

Figure 14. Feature-class components of the bathymetric TIN or ESRI Terrain.

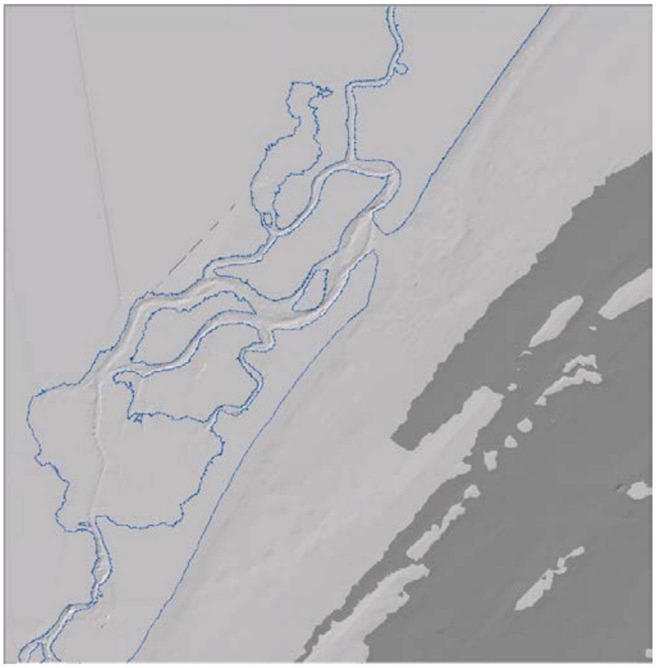

Figure 15. Example of resultant TIN surface and breaklines in an ESRI Terrain.

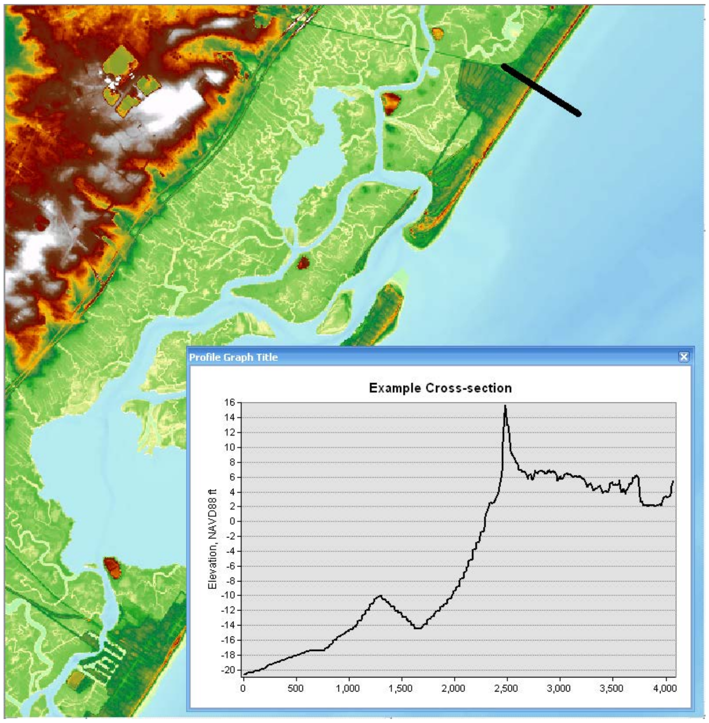

Figure 16. Example of final seamless DEM and cross-sectional representation. Enforcement of the shoreline allows seamless interpolation of the bathymetry up to the lower extent of the topography.

Seamless DEM development involved the following steps:

1. Creation of topographic and bathymetric masks;
2. Extraction of county-specific bathymetric data from full dataset;
3. Evaluation of data for missing features (for example, an isolated topographic island would otherwise be a data void if not inserted);
4. Mosaicking of topographic and bathymetric DEMs to new raster. This process enforced existing cell location of topographic raster to prevent re-interpolation of topographic elevations (clip raster set to topographic DEM);
5. Evaluation of seam transition from bathymetry to topography (Figure 16, for example);
6. Verification that no data voids are present except for the bathymetric/topographic data seam;
7. Execution of algorithm that identifies and fills voids at seam with nearest neighbor interpolation;
8. Execution of independent quality control of the data, including documentation and disclosure of identified problems;
9. Resolution of comments;
10. Submission of revised data for QA/QC backcheck; and
11. Export of dataset at resolution of 32.8 feet (10 m) to support surface elevation interpolation to the ADCIRC mesh.

3.2 ADCIRC TERRAIN

Unlike other aspects of coastal floodplain determination that require a high-resolution DEM, ADCIRC requires surface elevations at a more coarse resolution. For example, the ADCIRC model mesh created for the Region II Storm Surge Study has a nominal node spacing (horizontal resolution of elevation points) of approximately 260 feet (80 m). Also, limitations in the ADCIRC mesh-editing software, Surface-water Modeling System (SMS), do not support working with datasets at the resolution required for coastal floodplain analysis. Resampling of the seamless DEMs at an appropriate lower resolution meets the terrain needs of ADCIRC and also reduces the data density to workable levels for SMS.

The high-resolution, seamless DEMs were therefore reduced to a cell size of 32.8 feet (10 m) to represent overland terrain and small embayments for the ADCIRC mesh development. One concern of coarsening the topographic dataset is loss of fidelity for small ridge or ridge-like features that may obstruct the flow of water. To overcome this, such features were identified and extracted to vector features in a pre-processing phase of the mesh generation process using the full resolution DEMs. Further details of this feature extraction process can be found in the Region II Storm Surge Project Mesh Development Report (RAMPP, 2014).

Bathymetry data were also prepared to support generation of the offshore mesh using the Localized Truncation Error Analysis (LTEA) method. Node spacing in the ADCIRC mesh ranged from 260 feet (80 m) at the shoreline to more than 3,300 feet (1,000 m) offshore. To best support ADCIRC data requirements, the bathymetry was resampled into four different resolutions, depending on depth, as shown in Figure 17.

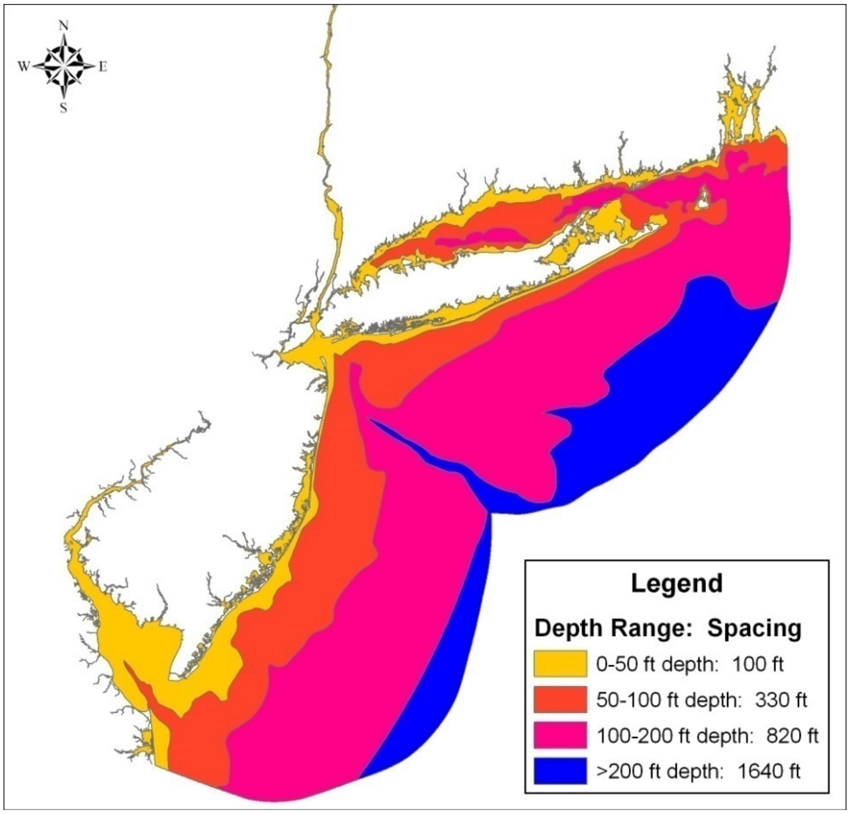

Figure 17. Resampled bathymetric DEM cell sizes for application to ADCIRC LTEA.

SECTION FOUR SUMMARY

To conduct storm surge modeling, coastal hazard analyses, and floodplain mapping for coastal counties in FEMA Region II, seamless DEM products were created using the most up-to-date topographic and bathymetric data available at the time of the study. Various topographic and bathymetric data sources were used to provide coverage throughout the region including NOAA, NASA, USGS, USACE, NGA, FEMA, and the State of New York.

Two separate DEM products were developed for the different phases of the study:

- A seamless DEM with a 10-m horizontal resolution for storm surge modeling
- County-by-county seamless DEMs with 2-m horizontal resolution for coastal hazard analysis and mapping

The final seamless DEM products were referenced to the Project Datum: horizontal datum of NAD83; New Jersey State Plane FIPS 2900, in feet; vertical datum of NAVD88, in feet.

SECTION FIVE REFERENCES

Advanced Circulation Model. The University of North Carolina at Chapel Hill, 2013. Retrieved from http://adcirc.org/.

Federal Emergency Management Agency, Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Surveying, Washington, Federal Emergency Management Agency, 2003.

Federal Emergency Management Agency, Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update, Final Draft. Washington, Federal Emergency Management Agency, February 2007.

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GEODAS (GEOphysical DAta System). National Geophysical Data Center, NOAA, 2010. Retrieved from http://www.ngdc.noaa.gov/mgg/geodas/geodas.html.

RAMPP, 2014, Region II Storm Surge Project - Mesh Development, FEMA TO HSFE02-09-J-001, 2014

Appendix A

FEMA Accuracy Standards for Elevation Data

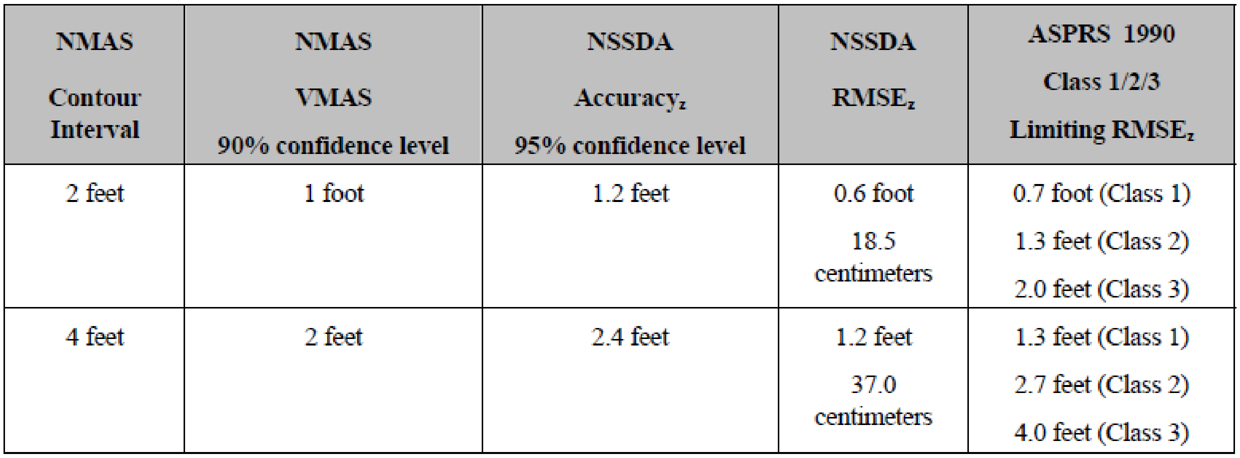
FEMA publishes standards for both horizontal and vertical accuracy of elevation products for FIS products in Appendix A: Guidance for Aerial Mapping and Surveying of the FEMA G&S and PM No. 61 – Standards for LiDAR and Other High Quality Digital Topography. These standards are summarized in Tables A-1, A-2, and A-3, excerpted directly from FEMA Appendix A and Procedure Memorandum No. 61 (September 2010). Coastal data are normally held to the 2-foot contour interval requirement. Readers are encouraged to refer to the source documents for further information and discussion of these standards.

It should be noted that the G&S do not stipulate that these standards are applicable to storm surge model terrain data. Best practice is to use the best available data at the time of the effort. Thus, data that fail to meet FEMA floodplain mapping standards may be used for storm surge modeling, but may not be used in overland wave hazard analysis or coastal floodplain mapping.

Table A-1. Comparison of Horizontal Accuracy Standards

NMAS Map Scale	NMAS CMAS 90% confidence level	NSSDA Accuracy_r 95% confidence level	NSSDA RMSE_r	ASPRS 1990 Class 1/2/3 Limiting RMSE_r
1" = 500'	16.7 feet	19.0 feet	11.0 feet	7.1 feet (Class 1) 14.1 feet (Class 2) 21.2 feet (Class 3)

Table A-2. Comparison of Vertical Accuracy Standards



NMAS Contour Interval	NMAS VMAS 90% confidence level	NSSDA Accuracy_z 95% confidence level	NSSDA RMSE_z	ASPRS 1990 Class 1/2/3 Limiting RMSE_z
2 feet	1 foot	1.2 feet	0.6 foot 18.5 centimeters	0.7 foot (Class 1) 1.3 feet (Class 2) 2.0 feet (Class 3)
4 feet	2 feet	2.4 feet	1.2 feet 37.0 centimeters	1.3 feet (Class 1) 2.7 feet (Class 2) 4.0 feet (Class 3)

Table A-3. FEMA LiDAR Vertical Accuracy Standards

Equivalent Contour Accuracy	FEMA Specification Level	RMSEz	NSSDA Accuracy$_z$, 95% confidence level	SVA (target)	CVA (mandatory)
1 ft		0.30 ft or 9.25 cm	0.60 ft or 18.2 cm	0.60 ft or 18.2 cm	0.60 ft or 18.2 cm
2 ft	Highest	0.61 ft or 18.5 cm	1.19 ft or 36.3 cm	1.19 ft or 36.3 cm	1.19 ft or 36.3 cm
4 ft	High	1.22 ft or 37.1 cm	2.38 ft or 72.6 cm	2.38 ft or 72.6 cm	2.38 ft or 72.6 cm
5 ft		1.52 ft or 46.3 cm	2.98 ft or 90.8 cm	2.98 ft or 90.8 cm	2.98 ft or 90.8 cm
8 ft	Medium	2.43 ft or 73.9 cm	4.77 ft or 1.45 m	4.77 ft or 1.45 m	4.77 ft or 1.45 m
10 ft		3.04 ft or 92.7 cm	5.96 ft or 1.82 m	5.96 ft or 1.82 m	5.96 ft or 1.82 m
12 ft	Low	3.65 ft or 1.11m	7.15 ft or 2.18 m	7.15 ft or 2.18 m	7.15 ft or 2.18 m

Appendix B

County-by-County Data Sources and Processing

This section identifies the topographic data sources and geoprocessing methods for each county. QA and control protocols were followed in accordance with RAMPP's Quality Management Plan. Counties are presented by data source and State.

Topographic datasets that became available subsequent to the topography used for the surge study are also included in this summary. These data were not used for the surge modeling effort. Each of these datasets was processed according to the needs of the overland wave hazard analysis and floodplain mapping efforts for each geography. Further details on those datasets and documentation of processing may be found in the Technical Support Data Notebook (TSDN) for the geography of interest.

NEW JERSEY

Bergen, Hudson, Essex, Union, Middlesex, and Upper Monmouth Counties

LiDAR data for these counties was obtained from the LiDAR acquisition initiative lead by the U.S. National Geospatial-Intelligence Agency (NGA) in 2006 for the metropolitan New Jersey area. These data covered northern New Jersey counties, with complete coverage for Bergen, Hudson, Essex, Union, and Middlesex Counties, and partial coverage for Monmouth County. Although the LiDAR data were collected in point format, only raster format data were made available by the NGA through the USGS EROS data center. The data were provided in two formats, IMG and TIFF. Both datasets had a cell size of 3.28 feet (1 m), projection of UTM Zone 18N, and elevation (Z) units of meters. The coverage of both datasets was identical; the only noted difference between the two datasets was tile size, where the IMG dataset was observed to have smaller tiles compared to the TIFF. Since the smaller tile size provided more flexibility in terms of data management, the IMG files were preferred and utilized.

Data gaps in the dataset were noted along the shoreline in Hudson County, as shown in Figure B-1. The USGS EROS, as well as the NGA, undertook extensive coordination to locate and acquire the missing data. Neither agency was able to do so. The next best available dataset (USGS National Elevation Dataset (NED) 1/3 arc second (10 m) DEM) was acquired and used to fill in the missing areas.

Figure B-1. Areas of missing NGA LiDAR topography in Hudson County.

The table below summarizes pertinent metadata from these two datasets.

Date Collected	12/4/2006 to 2/11/2007
Agency	USGS
Data Originator	Sanborn
Format	Raster-IMG
Spatial Reference	UTM, Zone 18N
Horizontal Units	Meters
Horizontal Resolution	1 Meter
Horizontal Accuracy	≤1 Meter RMSE
Vertical Datum	NAVD88
Vertical Units	Meters
Vertical Accuracy	18.5 cm or about 0.6 ft according to the National Standard for Spatial Data Accuracy (NSSDA) Root Mean Square Error ($RMSE_Z$)
DATA MEET FEMA STANDARDS FOR OVERLAND WAVE ANALYSIS AND MAPPING[1]	

[1] Supplemental data for missing areas sourced from the USGS NED does not meet FEMA Standards for Overland Wave Analysis and Mapping. For additional information, see the Hudson County TSDN. See documentation for Ocean and Atlantic Counties for relevant NED metadata.

Data were processed on a county-by-county basis. The IMG tiles associated with each county were identified, then subset to a county-specific folder. The identified IMG files were then converted into XYZ files using the GlobalMapper software application. Next, an ESRI FGDB was established, and the XYZ files were loaded to a single multi-point feature class. A data boundary shapefile, created from the identified tile extent for each county, was also exported to the FGDB to be used as a data limit for the terrain. Next, an ESRI Terrain was built using ArcCatalog with pyramid levels having Z tolerance values of 0.25, 0.5, 1, 5, and 10 for Essex County and 0.25, 0.5, 1, 5, and 20 for Bergen, Hudson, Middlesex, Monmouth, and Union Counties. It should be noted that pyramid levels for terrains are often computed based on extent and have no influence on the DEM products for this effort, as all were exported from a pyramid level of 0. Then, an ESRI raster DEM was exported at a resolution of 6.56 feet (2 m) from the terrain using a pyramid level of "0." Finally, the DEM was re-projected to the project horizontal datum and the vertical units were converted to feet using a factor of 3.2808.

Lower Monmouth County, NJ

Surge Modeling Data: The NGA-sourced LiDAR had a limited extent and covered only the upper two-thirds of the county. The best available dataset for the southern extent of the county consisted of countywide, photogrametrically derived contours that also served as the base map for the effective FIS study in Monmouth County. The extent of coverage of this partial county dataset is shown in Figure B-2. Metadata for the county-wide contours are given below.

Date Collected	2003
Agency	Monmouth County Office of GIS
Data Originator	Buchart Horn, Inc.
Format	Vector contours, 2-Foot Interval
Spatial Reference	NAD 83, New Jersey State Plane
Horizontal Units	Feet
Horizontal Resolution	N/A
Horizontal Accuracy	Meets or exceeds ASPRS Class 1 accuracy standards for 1"=100' maps
Vertical Datum	NAVD88
Vertical Units	Feet
Vertical Accuracy	Meet or exceeds ASPRS Class 1 accuracy standards for 1"=100' maps. Equivalent to 1/3 the contour interval (±0.67 ft)
DATA MEET FEMA STANDARDS FOR OVERLAND WAVE ANALYSIS AND MAPPING	

The required coverage for the southern portion of Monmouth County was subset from the countywide contour dataset. These features were then loaded as a polyline feature into a FGDB, and an ESRI Terrain surface elevation model was generated for the southern extent of the county, with pyramid levels having Z tolerance values of 0.25, 0.5, 1, 5, and 10. Next, the terrain was exported to an ESRI raster DEM at a resolution of 6.56 feet (2 m) using a pyramid level of 0 and then clipped to the topographic mask established for the lower portion of the county. The coordinate extent of the upper Monmouth DEM was enforced during this step to avoid re-interpolation of the cell elevations during mosaicking. The lower portion was then mosaicked to the upper portion to create a countywide DEM. A small area of overlap (30 ft or 9.14 m) was allowed, and cell elevations were blended over this area during the mosaicking process. Finally, the DEM was clipped to the county-specific mask.

It should be noted that these data were used only in the storm surge modeling effort. LiDAR was collected in the spring of 2010 to support the coastal overland wave hazard and mapping effort.

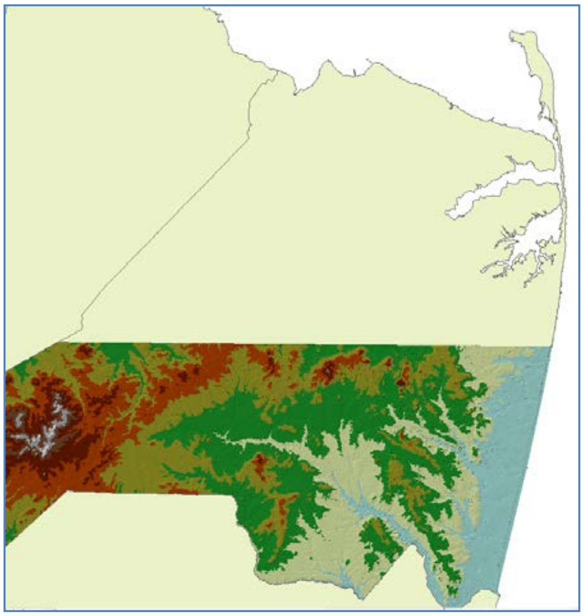


Figure B-2. ESRI Terrain depicting extent of supplemental contour data used for the storm surge modeling effort in the southern third of Monmouth County.

Overland Wave Hazard Modeling and Floodplain Mapping Data:

Elevation data for Atlantic, Ocean, and lower Monmouth Counties were derived from new LiDAR collected in support of the FEMA FIS update. These data consisted of a continuous collection effort in April 2010 that provided coverage for approximately 1,665 square miles. Metadata for the dataset is provided below.

Date Collected	April 2010
Agency	FEMA
Data Originator	RAMPP
Format	LAS
Spatial Reference	NAD 83, New Jersey State Plane
Horizontal Units	Feet
Horizontal Resolution	1.97 postings per square foot

Horizontal Accuracy	≤3.28 Feet RMSE
Vertical Datum	NAVD88
Vertical Units	Feet
Vertical Accuracy	NSSDA Fundamental Vertical Accuracy (FVA) at 95% confidence level = 0.35 ft, consolidated accuracy = 0.43 ft.
DATA MEET FEMA STANDARDS FOR OVERLAND WAVE ANALYSIS AND MAPPING	

LiDAR data for Upper and Lower Monmouth County was merged to develop a continuous terrain coverage for overland wave modeling in Monmouth County. Ground points from the LAS tiles in Lower Monmouth were converted to a multipoint feature class within an FGDB. The Upper Monmouth raster was converted to a point file and imported to the FGDB. The ESRI Terrain was created within an FGDB with pyramid levels representing Z tolerance values of 0.25, 0.5, 1, 2.5, 5, and 10 using ArcCatalog. An ESRI raster DEM was then exported at a resolution of 5 ft (1.5 m) from the ESRI terrain using a pyramid level of 0.

Ocean and Atlantic Counties, NJ

Ocean and Atlantic Counties had separate datasets for storm surge modeling and coastal hazard analysis and mapping. Details for each of these datasets are provided below.

Storm Surge Modeling Data: The best available dataset for Ocean and Atlantic Counties consisted of the USGS NED 1/3 arc second (10 m) DEM. Data for each county were retrieved from the USGS National Map Seamless Server (http://seamless.usgs.gov/) in ESRI raster format. The NED data available for these two counties was out of date (in some cases over 50 years old) and had poor vertical accuracy (on the order of meters). Vertical accuracy is not directly reported by USGS for NED quads. Maune (2007)[1] reports absolute vertical RMSE for NED data derived from "LineTrace+" (cited as LT4X in NED metadata) production method, as used for these counties, as 7.12 ft (2.17 m). It should be noted that these data do not meet FEMA standards and will only be used in support of storm surge modeling.

Date Collected	Not Available
Agency	USGS
Data Originator	USGS
Format	ASCII Raster
Spatial Reference	NAD83, Geographic Coordinate System
Horizontal Units	Decimal Degrees

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[1] Maune, D., ed., 2007, Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd edition, Bethesda, Md., American Society for Photogrammetry and Remote Sensing.

Horizontal Resolution	32.8 Feet
Horizontal Accuracy	Not Available
Vertical Datum	NAVD88
Vertical Units	Meters
Vertical Accuracy	7.12 ft RMSE typical for LT4X method[1]
ACCEPTABLE FOR SURGE MODELING ACCORDING TO FEMA G&S	

Following retrieval, data were re-projected to the project horizontal datum, and vertical units were converted to feet using a factor of 3.2808. Grid cell size was forced from about 30 feet to 32.8 feet (10 m). These data are acceptable for surge modeling applications per FEMA G&S, but do not meet standards for overland wave hazard analysis and floodplain mapping.

Coastal Overland Wave Hazard Modeling and Floodplain Mapping Data:

Elevation data for Atlantic, Ocean, and lower Monmouth Counties were derived from new LiDAR collection in support of the FEMA FIS update. These data consisted of a continuous collection effort in April 2010. Metadata for the dataset are provided below.

Date Collected	April 2010
Agency	FEMA
Data Originator	RAMPP
Format	LAS
Spatial Reference	NAD 83, New Jersey State Plane
Horizontal Units	Feet
Horizontal Resolution	1.97 postings per square foot
Horizontal Accuracy	≤3.28 ft RMSE
Vertical Datum	NAVD88
Vertical Units	Feet
Vertical Accuracy	NSSDA Fundamental Vertical Accuracy (FVA) at 95% confidence level = 0.35 ft, consolidated accuracy = 0.43 ft.
DATA MEET FEMA STANDARDS FOR OVERLAND WAVE ANALYSIS AND MAPPING	

Data were processed collectively for the entire area of interest. Ground points from the LAS tiles were converted to a multipoint feature class in a FGDB. The project boundary provided by FEMA was imported as a feature class to be used as a data limit for the ESRI Terrain. The hydro lines shapefiles compiled by the LiDAR vendor were imported as feature classes to be used as hydro-flattening lines. The ESRI Terrain was built with pyramid levels representing Z tolerance values of 0.25, 0.5, 1, 2.5, 5, and 10 using ArcCatalog. An ESRI raster DEM was then exported at a resolution of 10 feet from the ESRI Terrain using a pyramid level of 0.

Burlington County, NJ

Burlington County had separate datasets for storm surge modeling and coastal hazard analysis and mapping. Details for each of these datasets are provided below.

Storm Surge Modeling Data: Topographic coverage of Burlington County was provided by the FEMA Region II Support Center. These data consisted of 5-foot vector contours and a TIN. The TIN was comprised of a combination of the 5-foot contours, intermediate contours, breaklines, and spot elevation points for ground and water. Metadata for the base contour dataset are summarized in the following table.

Date Collected	April 2005
Agency	Delaware Valley Regional Planning Commission
Data Originator	BAE Systems
Format	Vector Contours, 5-Foot Interval
Spatial Reference	NAD83, New Jersey State Plane
Horizontal Units	Feet
Horizontal Resolution	N/A
Horizontal Accuracy	Meets NSSDA 1998 Standards Maximum RMSE for 95% of checkpoints 5 feet or better
Vertical Datum	NAVD88
Vertical Units	Feet
Vertical Accuracy	Meets NMAS standards for 1"=200' maps, 5' contour equivalent
ACCEPTABLE FOR SURGE MODELING ACCORDING TO FEMA G&S	

The provided TIN was converted to a raster DEM with a cell size of 6.56 ft and then clipped to the spatial limits of the study area.

Coastal Overland Wave Hazard Modeling and Floodplain Mapping Data:

Elevation data for Burlington County were derived from new LiDAR collection in support of the FEMA FIS update. These data consisted of a collection effort in 2011. Metadata for the dataset are provided below.

Date Collected	March 25, 2011 through April 21, 2011
Agency	FEMA
Data Originator	Laser Mapping Specialists, Inc
Format	LAS
Spatial Reference	UTM, Zone 18N
Horizontal Units	Meters
Horizontal Resolution	1 Meter
Horizontal Accuracy	0.6 Meter RMSE

Vertical Datum	NAVD88
Vertical Units	Meters
Vertical Accuracy	13.2 cm or about 0.43 ft, according to the National Standard for Spatial Data Accuracy (NSSDA) Root Mean Square Error (RMSE$_Z$)
DATA MEET FEMA STANDARDS FOR OVERLAND WAVE ANALYSIS AND MAPPING	

Data were processed collectively for the entire area of interest. Ground points from the LAS tiles were converted to a multipoint feature class within an FGDB feature dataset. A project boundary was created and imported into the feature dataset as a feature class and was used as the data extent for the ESRI Terrain. The ESRI Terrain was built with pyramid levels representing Z tolerance values of 0.25, 0.5, 1, 5, and 10 using ArcCatalog. An ESRI raster DEM was then exported at a resolution of 10 feet from the ESRI Terrain using a pyramid level of 0.

Cape May, Cumberland, and Salem Counties, NJ

Elevation data for Cape May, Cumberland, and Salem Counties were derived from LiDAR. Two datasets were used. The first was a continuous dataset collected in April 2008 that provided coverage for approximately 874 square miles of Coastal Area Facility Review Act (CAFRA) areas within the three counties. These data were provided by USGS EROS. The second dataset was acquired in March 2009 and provided additional coverage in Salem County, sourced from the New Jersey Department of Environmental Protection. Metadata for each dataset are provided below.

Metadata summary for Cape May, Cumberland, and Salem Counties (CAFRA areas):

Date Collected	April 2008
Agency	USGS
Data Originator	Photo Science, Inc.
Format	LAS
Spatial Reference	NAD83 New Jersey State Plane
Horizontal Units	Feet
Horizontal Resolution	Average of 1.58 postings per square meter
Horizontal Accuracy	≤1 Meter RMSE
Vertical Datum	NAVD88
Vertical Units	Meters
Vertical Accuracy	NSSDA Fundamental Vertical Accuracy (FVA) at 95% confidence interval = 13 cm, consolidated accuracy = 16 cm
DATA MEET FEMA STANDARDS FOR OVERLAND WAVE ANALYSIS AND MAPPING	

Metadata summary for Salem County supplemental data acquisition (non-CAFRA):

Date Collected	March 2009
Agency	USGS
Data Originator	Photo Science, Inc.
Format	LAS
Spatial Reference	NAD83 New Jersey State Plane, Feet
Horizontal Units	Feet
Horizontal Resolution	1.92 points per square meter
Horizontal Accuracy	≤1 Meter RMSE
Vertical Datum	NAVD88
Vertical Units	Meters
Vertical Accuracy	NSSDA FVA at 95% confidence interval = 29.4 cm, RMSE of 15 cm in open terrain land cover category.
DATA MEET FEMA STANDARDS FOR OVERLAND WAVE ANALYSIS AND MAPPING	

Data were processed on a county-by-county basis. The LAS tiles associated with each county were identified, then subset to a county-specific folder. The identified LAS files were then converted into multi-point shapefiles using the GlobalMapper software application. Next, an ESRI FGDB was established, and data were loaded to a single multi-point feature class. A data boundary shapefile, created from the identified tile extent for each county, was also exported to the FGDB to be used as a data limit for the terrain. Next, an ESRI Terrain was built with pyramid levels having Z tolerance values of 0.25, 0.5, 1, and 10 using ArcCatalog. An ESRI raster DEM was then exported at a resolution of 6.56 feet (2 m) from the terrain using a pyramid level of 0. Finally, the vertical units were converted to feet using a factor of 3.2808.

NEW YORK

Bronx, New York, Kings, Queens, and Richmond Counties

Storm Surge Modeling Data: A license agreement was established between RAMPP and NYC DOITT to facilitate use of the DOITT base map. Topographic data were provided in two formats: a raster product with a 9.84 foot (3 m) horizontal resolution and a vector product consisting of 2-foot elevation contours. Initially, topographic coverage was generated from the raster product. Quality control of this product cited significant issues with the surface representation, predominately consisting of street centerlines coded with incorrect or false elevations. Because of these issues, the study team decided to use the 2-foot vector contour data as a topographic base. These data were sourced from CONTOUR feature class in the NYC

Planimetrics_Data geodatabase provided by NYC DOITT. Metadata for this source are summarized in the following table.

Date Collected	2001-2002
Agency	NYC DOITT
Data Originator	NYC DOITT
Format	Vector contours
Spatial Reference	NAD 83 New York State Plane, Long Island Grid
Horizontal Units	Feet
Horizontal Resolution	N/A
Horizontal Accuracy	ASPRS Class 1 horizontal mapping standards
Vertical Datum	NAVD88
Vertical Units	Feet
Vertical Accuracy	ASPRS Class 2 vertical accuracy standard, 95% accurate to ±2 ft
ACCEPTABLE FOR SURGE MODELING ACCORDING TO FEMA G&S (Mapping standards do not apply, best available data, see Appendix A in this report for further information) NOT USED FOR DETAILED OVERLAND WAVE ANALYSIS AND FLOODPLAIN MAPPING	

The originating contour feature class was subset into county-by-county coverage. The subset contours were then loaded as a polyline feature into a FGDB, and an ESRI Terrain surface elevation model was generated for the countywide extent with pyramid levels having Z tolerance values of 0.5, 1, 2.5, 5 for Bronx, Kings, and New York Counties; 0.5, 1, 2.5, 5, 10 for Queens County; and 0.5, 1, 2.5 for Richmond County. The final step was to export the 0 pyramid level terrain to an ESRI raster DEM at a resolution of 6.56 feet (2 m) and clip it to the topographic mask established for each county.

Coastal Overland Wave Hazard Modeling and Floodplain Mapping Data: LiDAR was collected in the New York City area in spring 2010. Under the DOITT license agreement, LiDAR LAS files were provided to RAMPP for use in the FIS studies. Data were utilized in the native New York State Plane datum. Metadata are summarized below:

Date Collected	April-May 2010
Agency	Hunter College, City University of New York
Data Originator	Sanborn Map Company
Format	LAS
Spatial Reference	NAD83, New York State Plane, Long Island Grid

Horizontal Units	Feet
Horizontal Resolution	0.7 meter ground sampling distance
Horizontal Accuracy	10 cm RMSE
Vertical Datum	NAVD88
Vertical Units	Feet
Vertical Accuracy	Fundamental Vertical Accuracy tested to 0.048 m at 95% confidence level in open terrain
DATA MEET FEMA STANDARDS FOR OVERLAND WAVE ANALYSIS AND MAPPING	

Data were processed collectively for the entire area of interest. Ground points from the LAS tiles were converted to a multipoint feature class in a, FGDB. The ESRI Terrain was established using ArcCatalog. An ESRI raster DEM was then exported at a resolution of 10 feet from the ESRI Terrain using a pyramid level of 0. Further information on this product may be found in the New York City Coastal FIS TSDN.

Westchester County, NY (Long Island Sound)

Storm Surge Modeling Data: Tiled topographic vector contours were retrieved from the Westchester County GIS web portal* in AutoCAD "dwg" format. Metadata are summarized below.

**http://giswww.westchestergov.com/gismap/Topo_download_help.htm*

Date Collected	April 2004
Agency	Westchester County
Originator	Buchart Horn, Inc.
Format	AutoCAD .dwg format, 2 ft contour interval
Spatial Reference	NAD 83, Geographic Coordinate System
Horizontal Units	Decimal Degrees
Horizontal Resolution	N/A
Horizontal Accuracy	Meet or exceed NMAS, ±3.33 ft @ 90% confidence interval
Vertical Datum	NAVD88
Vertical Units	Feet
Vertical Accuracy	Meet or exceed NMAS, contours ±1 ft
DATA MEET FEMA STANDARDS FOR OVERLAND WAVE ANALYSIS AND MAPPING	

Contour data were converted from AutoCAD .dwg format to ESRI polyline shapefile format and merged into a continuous dataset for the coastal floodplain along the Long Island Sound shoreline of Westchester County. The shapefile was then imported into an ESRI FGBD as a polyline feature class. An ESRI Terrain was generated from this coverage with pyramid levels having Z tolerance values of 0.5, 1, 2.5, and 5, and then exported from the 0 pyramid level to the project datum as an ESRI DEM with a cell size of 6.56 feet (2 m). Finally, the DEM was clipped to the study area using a vector mask.

Coastal Overland Wave Hazard Modeling and Floodplain Mapping Data: DEM tiles were retrieved from the New York State "Orthos Online" web mapping service (http://www.orthos.dhses.ny.gov/. Metadata are summarized below:

Date Collected	February 2012
Agency	New York State Department of Environmental Conservation, NOAA
Data Originator	Photo Science, Inc.
Format	ERDAS Imagine (.img)
Spatial Reference	NAD83, UTM Zone 18N
Horizontal Units	Meters
Horizontal Resolution	1.0 m or better
Horizontal Accuracy	Stated compiled to 100-cm horizontal accuracy
Vertical Datum	NAVD88
Vertical Units	Meters
Vertical Accuracy	0.051 m RMSE, calculated from classified LAS files
DATA MEET FEMA STANDARDS FOR OVERLAND WAVE ANALYSIS AND	

DEM tiles were retrieved and mosaicked into a continuous coverage across the study area. The mosaiced DEM was then re-projected and vertical units were converted to feet. The DEM was clipped to the zero NAVD88 shoreline and merged with the study area bathymetry to create a seamless data product. Further information on this product may be found in the Westchester County FIS TSDN.

Nassau County, NY

The base topographic data consisted of contour data provided by Nassau County for the previous FIS restudy of that county. These data consisted of vector contours derived from April 1993 stereo photography and New York State High Resolution Statewide Digital Orthoimagery Program photography collected in April 2004. Data were only needed in western Nassau County, and these were used to transition the ADCIRC mesh to a lower resolution bathymetry. This was the only representation outside the direct study area.

Data were extracted and re-projected to the project datum for the study area from the seamless DEM prepared for the Nassau County FIS.

Date Collected	Based on 1993 Stereo Orthoimagery
Agency	Nassau County
Originator	Geomaps International
Format	Vector Contours, 2-foot Interval
Spatial Reference	NAD83, New York State Plane, Long Island Grid
Horizontal Units	Feet
Horizontal Resolution	N/A
Horizontal Accuracy	Unknown
Vertical Datum	NGVD29
Vertical Units	Feet
Vertical Accuracy	2' Contour Equivalent
Previous FIS Study Data	

Hudson River Valley, including Rockland, Westchester, Putnam, Orange, Dutchess, Ulster, Columbia, Greene, Albany, and Rensselaer Counties, NY

The data source for the Hudson River Valley counties was the USGS NED 1/3 arc second (10 m) DEM. Data were retrieved from the USGS National Map Seamless Server in ESRI raster format. It should be noted that these data were used only in support of storm surge modeling, and these counties are outside of the detailed study area.

Date Collected	Not Available
Agency	USGS
Data Originator	USGS
Format	ASCII Raster
Spatial Reference	NAD83, Geographic Coordinate System
Horizontal Units	Decimal Degrees
Horizontal Resolution	32.8 ft
Horizontal Accuracy	Not Available

Vertical Datum	NAVD88
Vertical Units	Meters
Vertical Accuracy	7.12 ft RMSE typical for LT4X method[1]
ACCEPTABLE FOR SURGE MODELING ACCORDING TO FEMA G&S (Mapping standards do not apply; use best available data, see Appendix A in this report for further information) NOT USED FOR DETAILED OVERLAND WAVE ANALYSIS AND FLOODPLAIN MAPPING	

Following retrieval, data were re-projected to the project horizontal datum, and vertical units were converted to feet using a factor of 3.2808. Grid cell size was forced from approximately 30 ft to 32.8 ft (10 m) during re-projection. Data were then extracted for the study area.

CONNECTICUT

Fairfield County, CT

LiDAR-derived topographic vector contours were leveraged from FIRM redelineation studies. Source data were vector-contour feature-layer deliverables to FEMA. Metadata are summarized below.

Date Collected	December 2006
Agency	FEMA
Data Originator	Dewberry
Format	ESRI Geodatabase, 2-foot contour interval
Spatial Reference	NAD 83, Connecticut State Plane Coordinates
Horizontal Units	Feet
Horizontal Resolution	N/A
Horizontal Accuracy	3-foot accuracy at 95% confidence level
Vertical Datum	NAVD88
Vertical Units	Feet
Vertical Accuracy	Source LiDAR tested 0.34 ft vertical accuracy at 95% confidence level in open terrain, tested 0.43 ft vertical accuracy at 95% confidence level in all land cover categories.
Previous FIS Study Data	

Contour data were converted and imported to an ESRI FGDB as a polyline feature class. The data were limited to an area of interest reaching from the Westchester/Fairfield County boundary to approximately 2 miles northeast. An ESRI Terrain was generated from this coverage having pyramid levels with Z tolerances of 0.5 and 1, and then exported from the 0 pyramid level to the project datum as an ESRI DEM with a cell size of 6.56 feet (2 m). The DEM was clipped to the study area using a vector mask, and then merged with the Westchester County, NY, DEM.