Hazus-MH Coastal Flood Model

FEMA Region IV Standard Operating Procedure for Coastal Flood Hazard and Loss Analysis

Original: August 2008
Updated: August 2012

FEMA

Credits[F1]

Original Prepared by:

H. E. "Gene" Longenecker
Senior Physical Scientist
FEMA Region IV MT-Risk Analysis
herbert.longenecker@fema.dhs.gov

Reviewed by:

Doug Bausch
Senior Physical Scientist
FEMA Region VIII MT
douglas.bausch@fema.dhs.gov

Joe Rachel
Hazus Coordinator
FEMA Region IV MT
joseph.rachel@fema.dhs.gov

Dr. Dan Allen
GIS Unit Leader
FEMA-DR-1604-MS Katrina
Biloxi Recovery Office
daniel.allen@ fema.dhs.gov

Validated by:

Jason Trzaska
GIS Analyst
FEMA-DR-1604-MS Katrina
Biloxi Recovery Office
jason.trzaska@fema.dhs.gov

2012 Update Prepared, Reviewed, and Validated by:

The FEMA Modeling Task Force and Region IV Risk Analysis Team

H. E. "Gene" Longenecker
Senior Physical Scientist
FEMA Region IV MT-Risk Analysis
herbert.longenecker@fema.dhs.gov

S. Moses Wilkins
Risk Analyst
FEMA Region IV MT-Risk Analysis
samuel.wilkins@fema.dhs.gov

Niclaos Almonor
Risk Analyst
FEMA Region IV MT-Risk Analysis
niclaos.almonor@fema.dhs.gov

Casey Zuzak
Risk Analyst
FEMA Region IV MT-Risk Analysis
casey.zuzak@fema.dhs.gov

Brandon Bolinski
Hurricane Program Manager
FEMA Region IV Response Division
Operations Planning Branch
brandon.bolinski@fema.dhs.gov

DRAFT

DRAFT

Table of Contents

Credits i
Table of Contents ii
Overview of Hazus Coastal Flood Methodology Development iii
Points of Contact v
File Management Recommendation vi
The SLOSH Model viii
Software and Data Requirements x
CONOPS: Proposed Timelines xii
Pre-Event Analyses xii
Event Analysis xiii
Post-Event Analyses xiv
Summary of the Process 1
The Process 2
Introduction 2
Step 1: Convert SLOSH MOM Grids to Points 5
Step 2: Convert NGVD29 to NAVD88 12
Step 3: Interpolate the Flood Surface 22
Step 4: Hazus Depth Grid Tool 24
Step 5: Import Depth Grid and Analyses 28
Step 6: Archive Results and HPR 34
Conclusion and Future Work 37
Conclusion 37
Future Work 37
Appendix A: How to Install the ET GeoWizards Software 39
Appendix B: Hurricane Dolly CONOPS 40
Appendix C: Python Script to Clip Multiple Counties 42
Appendix D: Applications and Available Products of the CFLA 45
Hurricane Storm Surge 45
Riverine Inundation and High Water Marks 52
Extratropical Cyclone Surge Analysis 53
Tsunami Inundation Analysis 55

DRAFT

Appendix E: Planning Assumptions 58
Appendix F: CFLA Limitations 59
Appendix G: Attribute Reference Guide 60
Appendix H: Exercise Use 62
Appendix I: FEMA & USGS IMMAGE Project 83
List of Figures 84

DRAFT

Overview of Hazus Coastal Flood Methodology Development

Following the relatively quiet hurricane season of 2006, an effort was undertaken by Planning and Mitigation specialists from FEMA Regions IV and VIII to create an atlas of storm surge loss estimations using the HAZUS-MH MR2 Coastal Flood Module. This effort was primarily targeted on Region IV coastal counties which may experience storm surge during the upcoming 2007 hurricane season, yet the importance of the project noted that all hurricane-prone counties on the east coast of the United States should be included in the loss atlas project. However, this project was ultimately suspended due to limited human and material resources, as well as time requirements: the HAZUS-MH MR2 coastal flood model commonly ran for more than 36 to 48 hours per county, and with more than 200 counties on the east coast, the project would consume thousands of hours of processing and production time.

Beginning in Summer 2007, a validation study for the Hazus-MH Coastal Flood Module was undertaken by Planning and Mitigation specialists from FEMA Regions IV and VIII. The immediate goal of this project was to validate the coastal flood model using historical flood and loss data captured following Hurricane Katrina in Hancock, Harrison, and Jackson Counties, Mississippi. The results of this study were completed in late Summer 2008 and were produced separately from this report; however, the Mississippi validation study has yielded several important developments. First, the HAZUS-MH MR3 Coastal Flood Methodology is sound and valid. Second, the implementation of user-defined flood depth grids is the most viable method for timely analysis of coastal floods. Third, the library of depth-to-damage functions supplied in the coastal flood model (from FIA and USACE analyses) were once the best available data, but must be updated to reflect observed loss data for site-specific floods. Fourth, and most important to the development of this SOP, NOAA's SLOSH (Sea, Land, Overland Surges from Hurricanes) model analyses can be easily incorporated into the HAZUS-MH MR3 Coastal Flood model as a user-supplied depth grid with some moderate GIS manipulation and intermediate skill.

With the 2008 hurricane season impending, a workshop was held at the Region IV RRCC in June 2008 with specialists from Planning, Mitigation, Risk Analysis Branch, MapMod, IA-TAQ, and the Hurricane Program, representing Regions IV, VI, VIII, HQ and the MS-TRO. This workshop proposed and accepted the following methodology for a Hazus Coastal Flood Loss Atlas (CFLA) in support of regional risk analysis activities:

1. That, given the intricacies and time requirements of the coastal flood modeling, the flood loss atlas will be scenario-driven and should be accomplished prior to response and recovery activities;

2. That, building on the hazard and vulnerability analyses conducted for the Hurricane Evacuation Studies and the pre-existing partnerships between FEMA, NOAA, and USACE, the SLOSH Maximum of Maximums (MOMs) will drive Hazus coastal flood loss scenarios; and

3. That the specific methodology for this project is set out of this SOP as follows.

In 2009, the Risk Analysis Team released the first updated of the Coastal Flood Loss Atlas. Similar to the initial version, Version2.0 only included coastal counties in FEMA Region IV and was created using

HAZUS-MH MR3. The reason for the updated was that they NHC released an updated to the SLOSH MOMs data.

The next updated to the CFLA took place in 2010. In this version, the CFLA was expanded to include FEMA Region VI (TX and LA), and this version (Version2.1) was ran using HAZUS-MH MR4 patch 1, and the same version of SLOSH.

The 4th updated to the CFLA (Version3.0) was released in January 2012 and was created using HAZUS-MH MR4 patch 2 for FEMA Regions I, II (excluding PR and VI), III, IV, VI. This was the most significant release of the CFLA to date. It includes over 100 attributes for over 225 counties along the entire Gulf of Mexico and Atlantic coastlines. This version also includes several inland counties that receive coastal surge flooding via rivers that are influenced by tides. The Risk Analysis Team is also in coordination with their modeling counterparts at the United States Geological Survey (USGS) to develop a web portal for quick viewing of the CFLA at the Census Block-level.

The Risk Analysis Team has outlined the next two versions of the CFLA (CFLA V4.0 – Summer 2012; CFLA V5.0 – Summer 2013). CFLA V4.0 will include several exposure and social metrics, historical loss data, inland counties that experience coastal surge flooding, historic strike data, and a mean surge value. This version of the CFLA will include the US Virgin Islands, Lake Okeechobee, Puerto Rico, and Hawaii. CFLA V5.0 will incorporate more local data (where available), including a parcel level analysis, and NFIP policy and DFIRM review. This version will also expand from tropical cyclone induced surge flooding, and include extratropical cyclone induced flooding and tsunami flooding.

DRAFT

Points of Contact

Hazus Coastal Flood Methodology:

H. E. “Gene” Longenecker, Senior Physical Scientist, FEMA RIV MT
Doug Bausch, Senior Physical Scientist, FEMA RVIII MT
Jesse Rozelle, Risk Analyst/Regional GIS Coordinator, FEMA RVIII MT
S. Moses Wilkins, Risk Analyst, FEMA RIV MT
Niclaos Almonor, Risk Analyst, FEMA RIV MT
Casey Zuzak, Risk Analyst, FEMA RIV MT

Coastal Flood Loss Atlas Methodology:

H. E. “Gene” Longenecker, Senior Physical Scientist, FEMA RIV MT
S. Moses Wilkins, Risk Analyst, FEMA RIV MT
Niclaos Almonor, Risk Analyst, FEMA RIV MT
Casey Zuzak, Risk Analyst, FEMA RIV MT

DRAFT

File Management Recommendation

The goal of this SOP is to generate raster depth grids from the SLOSH MOMs for each basin United States coastline at risk from hurricane storm surge flooding. Since there are more than 70 coastal counties within Region 4 alone and nearly 300 counties that receive some sort of coastal flooding, there will be a great number of files, both raster and vector, which will be generated for use in Hazus as well as an even greater number of temporary files—all of which require valuable, limited disk space.

It is recommended that depth grids and associated vector polygons be stored in a file structure similar to Figure 1. A temporary directory exists separate from the directory containing the depth grids and polygons. The temporary directory, in this case, contains the IDW flood surfaces and other files generated during depth grid creation process. Ultimately, these files are useless once the depth grid and polygons have been generated, and they can be deleted from permanent storage at that point. The temporary directory can become quite large at times, and the idea is to occasionally delete all files within this folder to preserve precious disk space.

In Figure 1, the depth grids and polygons are organized according to SLOSH basin and county name. The county name folder contains the raster depth grid, and the vector polygons for each county. For Region 4 (or the east coast), there will be duplicate county names encountered, so we suggest using a including the state abbreviation in the naming convention to avoid duplication (and confusion when referencing county depth grids). Furthermore, we recommend the vector polygons be named with the name of the county, the NHC's SLOSH basin abbreviation, the letter "c" and the MOM category number, and either "dg" for the raster files or "boundary" for the vector files (e.g. ms6c1dg represents the raster depth grid for Hancock County generated from the MS6 SLOSH basin using a category 1 MOM).

Since a large number of files can be created with this SOP, we highly recommend having a file management strategy in place prior to generating GIS files or Hazus analyses. The following table summarizes the amount of depth grid file data generated for the three coastal counties of Mississippi but does not include temporary working data generated in coincidence.

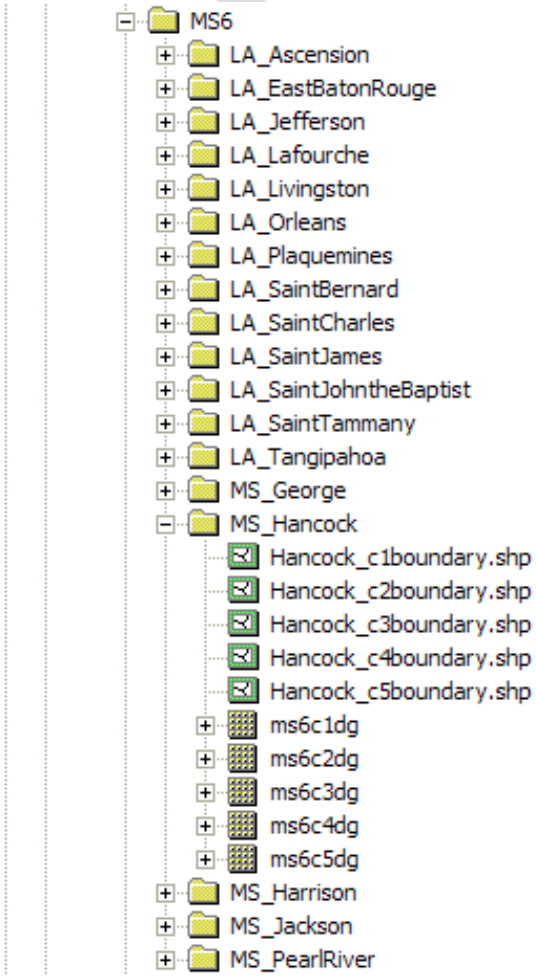


Figure 1. Sample file management.

DRAFT

County	3-meter	10-meter	30-meter
Hancock	4.8 GB	>200 MB	51.5 MB
Harrison	2.3 GB	>150 MB	66.8 MB
Jackson	8.7 GB	>200 MB	73.8 MB

Figure 2. Disk space usage for Mississippi coast depth grids

At this point only the depth grid files have been mentioned, yet the Hazus study regions, DEM and HPR (compressed study region) files also demand bountiful disk space. The following is a list of components for the Hancock County, Mississippi study region, HPR, and associated depth grids.

Study Region size on disk:	1,000 MB
Study Region DEM size on Disk:	33 MB
Study Region depth grid (from SLOSH):	51 MB
Study Region HPR:	183 MB
Total Study Region Size:	1.267 GB

DRAFT

The SLOSH Model

The SLOSH model, developed during the 1970s by NOAA's Techniques Development Laboratory, consists of a hurricane wind model which drives a storm surge model. Climatologic input parameters for the model include radius to maximum winds (in a perfect circle from the center of a hurricane), pressure, forward speed and track. Adjustments to the hurricane wind model give storms their asymmetric characteristics (i.e. northward moving storms have strongest winds in the front-right quadrant), and fixed coefficients for ocean surface drag, eddy viscosity and bottom slip are driven by the aforementioned meteorological conditions—thus, there are no variations from one geographic region to another. The geographic extent of the modeled surge surface is called a basin, and all SLOSH basins (with the exception of the Lake Okeechobee basin) use a telescoping polar coordinate system such that the finest resolution grid cells are over land (i.e. the area of interest for overland surges) and the lowest resolution cells are over water (pushing boundary conditions as far away from the areas of interest as possible). The model runs for 48 hours over water and 24 hours over land, for a total of 72 hours (maximum model runtime). The aforementioned meteorological data is input at 6-hour intervals, and the National Hurricane Center uses SLOSH operationally to forecast storm surge from hurricanes, with such forecasts being released to the public no earlier than 24 hours prior to landfall.

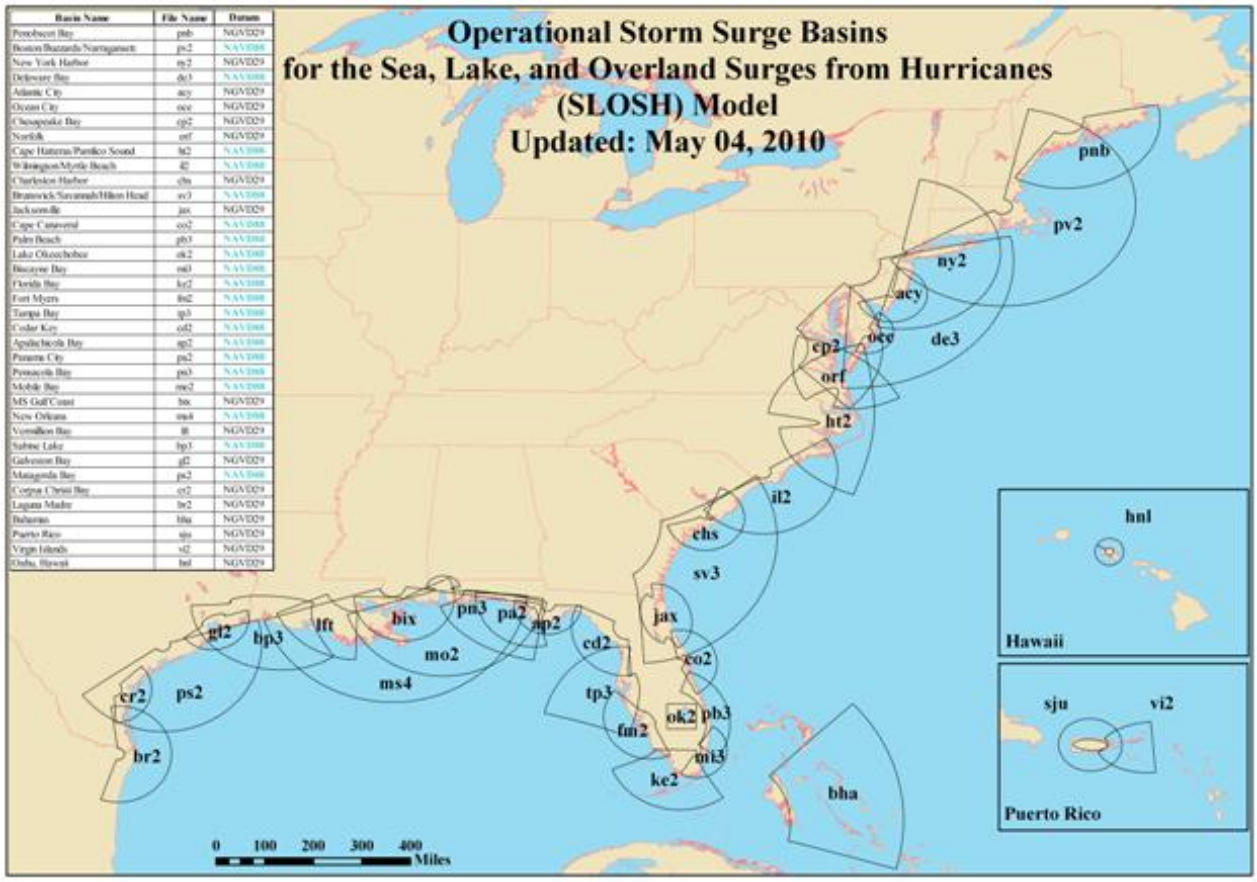


Figure 3. SLOSH basins provide hurricane surge estimates for the entire coastline of the United States, including Hawaii. (Source: NOAA, weather.gov)

Funded by the FEMA Hurricane Program and through a partnership between FEMA, NOAA, and the USACE, Hurricane Evacuation Studies (HES) are produced to provide emergency management officials information that will assist them in hurricane evacuation decision-making. Among the many facets of these studies, hazard and vulnerability analyses are performed for potential storm surges as predicted by the SLOSH model. Since forecasters cannot be certain about landfall locations of hurricanes, a composite of potential storm surges, called a Maximum Envelope of Water (MEOW), is developed within SLOSH basins which represents the maximum height of storm surge water in a given basin grid cell. This maximum water depth is determined as a maximum potential water height within each category of hurricane strength, representing the Maximum of Maximums (MOM). The MEOWs and MOMs for each hurricane category are used for coastal storm surge inundation mapping, and for then for evacuation planning per the HES. Using MEOWs eliminates the possibility that a critical storm track will be missed in which extreme storm surge values are generated.

Piggybacking on the pre-existing knowledge generated from the HES and the storm surge modeling expertise of NOAA, the SLOSH MOMs provide a sound basis for the HAZUS Coastal Flood Loss Atlas (CFLA). The maximum potential losses for study areas can be estimated with the HAZUS-MH Coastal Flood Module to correspond to the MOMs for Saffir-Simpson hurricane categories 1 through 5 for each county on the United States coastline at risk to tropical and extratropical cyclones. Upon activation of the FEMA NRCC and RRCC, the potential losses can be referenced as a planning tool for gauging an appropriate response; however, the categorical loss scenarios must be run well in advance of hurricane event activations due to time and processing limitations of the HAZUS model. Furthermore, SLOSH hindcast storm surge estimates can be used until high water mark data can be collected by PDA, Mitigation, or other field crews deployed through an interagency agreement or by a JFO, ERT, or local emergency management office. Collection of high water data in conjunction with the pre-run categorical loss scenarios provides a catalyst for HAZUS model validation studies to be conducted by internal FEMA resources.

Although several parameters are ignored in the model, including astronomical tides and inland flooding from rainfall, **SLOSH is accurate within +/- 20% of peak storm surges** when using known values for best fit track, intensity, and radius to maximum winds.

References

Shaffer, W.A., C.P. Jelesnianski, and J. Chen (1986). Hurricane Storm Surge Forecasting. Oceans, 18:1379-85.

Wiggert, V., and B.R. Jarvinen (1986). A Storm Surge Atlas for the Sabine Lake Area. NOAA Technical Memorandum NWS NHC 30.

DRAFT

Software and Data Requirements

In general, this coastal flood methodology involves the conversion of vector data to raster data for useful analysis in the GIS/HAZUS environment. Some ESRI/ArcMap-based processes require the ArcInfo license; however, since this license level is not readily available to all users, this coastal flood methodology employs recommended tools which can be used at the ArcEditor license level. The following items are necessary to employ this SOP:

General Software Requirements

- ESRI ArcGIS Version 9.3 SP1 or higher (ArcEditor license with Spatial Analyst)
- ET GeoWizards – A free GIS toolbox plug-in available from ET Spatial Techniques online at (versions available for both ArcGIS 9.3 and ArcGIS 10): http://www.ian-ko.com/ET_GeoWizards/gw_main.htm
- SLOSH MOM shapefiles – available for the National Hurricane Center
- USGS NED 30-Meter DEM – available online at (Region IV has compiled DEM's for all eastern and gulf coastal counties): http://seamless.usgs.gov/website/seamless/viewer.htm
- VERTCON – Vertical datum conversion software – available online at: http://www.ngs.noaa.gov/PC_PROD/VERTCON/
- HAZUS 2.0 Toolbox for ArcGIS – available from the Risk Analysis Team:
- \\r4li3f02\Hazus$\Applications\ESRI_Tools\HAZUS 2.0 Toolbox.tbx
- For all Hazus hardware and software requirements http://www.fema.gov/plan/prevent/Hazus/hz_reqmnts.shtm

Due to time, disk space, and processing limitations, we recommend using DEMs from the USGS NED. Although vertical errors may exist in the USGS NED, the accuracy level is sufficient to carry out Level-One HAZUS analyses as described herein. The coarse resolution of the 30-meter DEMs allows for rapid processing and decreased time and disk space requirements. Results from the HAZUS Coastal Flood Model validation study in Mississippi suggest that depth-to-damage functions derived using 3-meter, 10-meter or 30-meter DEMs are not statistically different. However, distribution of the flood surface at coarse resolutions may cause overestimation of losses as a result of cartographic generalization; furthermore, coupling with the limitations imposed by the temporal resolution of HAZUS Level-One base data, **this SOP intends to provide a base-level risk analysis for vulnerable coastal counties only**. Use of the SLOSH MOMs increases the quality of the hazard analysis; however, **uncertainty in loss estimation for HAZUS Level-One analysis is high and resulting analyses should be used judiciously.** Use of higher resolution data—including LiDAR, historical high water marks, improved damage functions and building stock—is recommended for future versions of the Coastal Flood Loss Atlas.

The USGS 30-meter NED completely covers all coastal counties and allows for rapid processing times and relatively high accuracy at this spatial resolution. **Moreover, the USGS 30-meter NED covers the entire US coastline, thus making the Region 4 process a nationally applicable standard.**

The SLOSH categorical MOMs provide maximum flood heights for each storm category, and will therefore provide maximum flood loss estimates for each storm category. The CONOPS for the SLOSH-HAZUS loss estimates specifies that all coastal counties within Region 4 and eventually the nation will be run and analyzed prior to operational response periods as dictated by impending tropical storms or hurricanes. See "Timeline" section below for further guidance.

The HAZUS Coastal Flood Loss Atlas should be revised with higher resolution data when and where available. The baseline Atlas will consist of hazard analyses performed at 30-meter spatial resolution for rapid development and preparedness; however, the use of LiDAR-derived ground elevations or interpolated flood surface provide much finer analyses to be performed. While pre-event LiDAR is available in many communities, post-event LiDAR missions are becoming a relative standard for response and recovery activities for all portions of the FEMA mission. More detailed analyses and development of the Coastal Flood Loss Atlas should incorporate LiDAR, gage data, and post-event high water marks as a development standard. See “Timeline” section below for further guidance.

DRAFT

CONOPS: Proposed Timelines

As discussed above, the Hazus Coastal Flood Loss Atlas intends to provide a dictionary of scenario-driven categorical losses for all coastal surge prone counties in the United States. The most immediate and predictable cause of coastal flooding in the United States is related to hurricane storm surge flooding, and the CFLA is oriented to provide a hurricane-category loss approach (the methods of this SOP can be used coastal flooding associated with extratropical cyclones). With limited resources available at any given time, this SOP proposes the following timelines:

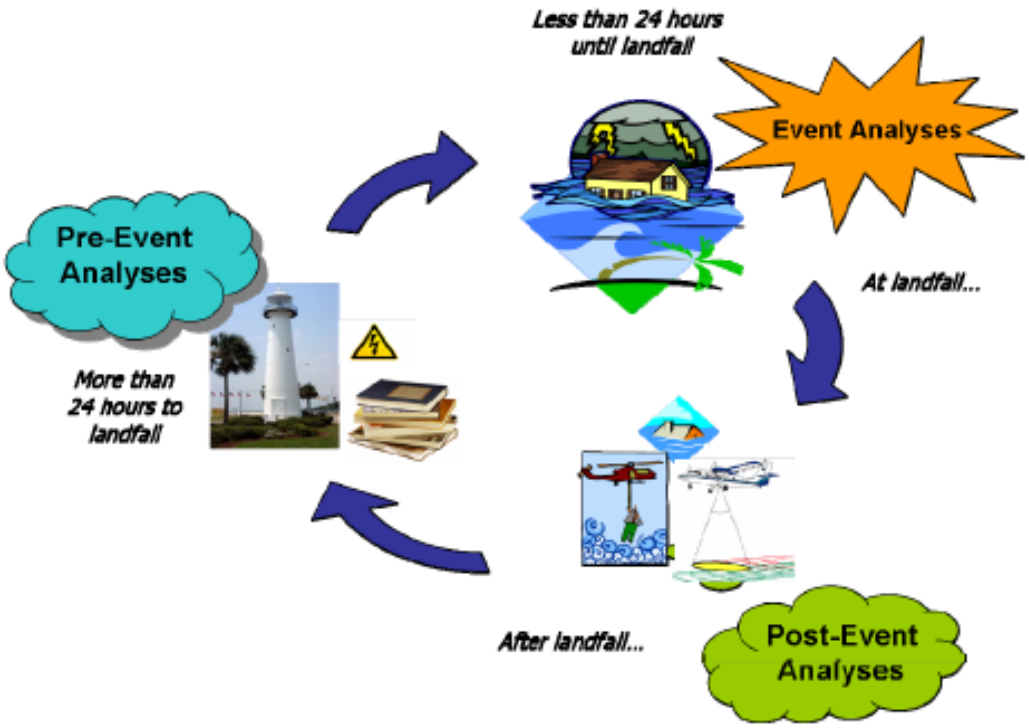


Figure 4. CONOPS Timeline.

Pre-Event Analyses

With more than 70 coastal counties in FEMA Region 4 along, it is nearly impossible to isolate a single county or group of counties which would be affected by a landfalling tropical storm or hurricane within the confines of a National Hurricane Center operational forecast (i.e. less than 120 hours/5 days). Estimating losses for five hurricane categories for each of the more than 70 coastal counties gives a total of more than 70 Hazus study regions, and more than 400 individual analyses. The time and disk space requirements are large; therefore **this SOP follows this pre-event timeline:**

- Analyses preformed **more than 24 hours prior to landfall** will be considered pre-event analysis
- All Region 4 counties shall be analyzed prior to RRCC activations using SLOSH MOMs for maximum loss estimates by hurricane category

- All available resources will perform loss estimates by hurricane category throughout the year, time, resources, and events permitting
- **The Hazus Coastal Flood Loss Atlas will be updated with the most current data** available including, but not limited to post-event LiDAR elevation models, river gage and high water mark data, hindcast SLOSH estimates, and any and all available building loss data reflecting damage and /or water depth data (e.g.) RSDE, NFIP)
- Pre-Event analyses shall provide the basis for the Coastal Flood Loss Atlas such that all available analyses may be referred to during Event activations, thereby providing maximum loss estimations per hurricane category

GOAL: To have maximum loss estimations per hurricane category available prior to event activation such that all analyses are complete and all vulnerability assets are identified.

GOAL: To provide a catalyst and the basis for validating the Hazus-MH Coastal Flood Module by establish baseline analysis

Event Analysis

As mentioned in the description of the SLOSH model, the National Hurricane Center may release to FEMA and other agencies shapefile-output from the operational SLOSH estimates for storm surge based on observed and forecast meteorological data captured in large part by hurricane hunter aircraft. These operational SLOSH estimates are released with every full advisory from the NHC—every six hours beginning at 0500 local time (i.e. 0500, 1100, 1700, and 2300 hrs). Use of the operational SLOSH shapefiles to generate HAZUS depth grids per this SOP's methodology will provide the best available loss estimation from coastal flooding **pursuant to the following timeline:**

- Analyses preformed **less than 24 hours prior to and after landfall** will be considered event analysis
- Event analysis will rely on quality-checked and verified operational SLOSH advisories from the National Hurricane Center through its FTP website
- Event analyses will be performed every six hours in accordance with full advisories from the National Hurricane Center when data provided is deemed acceptable for use in the Hazus Coastal Flood Model
- Event analysis will be limited in distribution to key RRCC decision makers under the assumption that climatological factors influencing storm intensity or landfall locations may cause wide variance in loss estimation, including unreasonable loss estimates

GOAL: To provide the best Hazus loss estimates in conjunction with the current and best available meteorological data and analyses from the National Hurricane Center

GOAL: To provide the best available risk analyses during preparedness, response, and recovery efforts as demanded by RRCC activations

DRAFT

Post-Event Analyses

The ubiquitous and bountiful data captured after landfall should be incorporated into the Hazus Coastal Flood Model to better refine and calibrate the loss estimation for specific local hazards, building data, damages, socio-economic, and infrastructural losses in general. Use of LiDAR, gauge data, and high water mark data will provide the best available depth grid for loss analyses, and will also prove to be a stepping stone to model validation when damage estimates are also incorporated into Hazus (such as from RSDE or NFIP data sets). Use of hindcast SLOSH estimates in addition to the aforementioned data will provide the best available loss estimation **pursuant to the following timeline:**

- Analyses preformed **greater than 24 hours after landfall** will be considered post-event analysis
- Post-event analyses should capitalize on the capturing of best-available ground elevations from LiDAR missions as well as from perishable data sources such as high water marks, gauge data, damage surveys, and other estimates
- Post-event analyses should provide superb data sources and opportunities to validate the Hazus-MH Coastal Flood Model in an "observed versus modeled" sense of loss estimation
- All post-event analysis shall be captured in the Hazus Coastal Flood Loss Atlas as snapshots of verified losses from specific hurricane events

GOAL: To create depth grids derived directly from storm related data (i.e. tidal gauge censors, and high water mark data), allow for remote preliminary damage estimates.

GOAL: To validate Hazus outputs through damage and loss estimates directly related to the specific event.

DRAFT

Summary of the Process

1. Load a county(s) within a SLOSH basin into ArcMap.
2. Load the corresponding SLOSH MOM shapefile into ArcMap.
3. Use ET GeoWizards (or any GIS tool – this is the only tool reviewed in this SOP) to extract centroid points from the SLOSH MOM shapefile.
4. Definition query for a category MOM to remove any null values.
5. Use the Select by Location feature in ArcMap and select all points within one (1) mile of the county(s) boundary.
6. Convert the SLOSH points to NAVD88 using VertCon to match the USGS NED DEM (this step may be omitted if the data is in the correct vertical datum).
7. Interpolate a flood surface (raster) using inverse distance weighting (IDW) in Spatial Analyst.
8. Use the Hazus toolbox to generate a flood depth grid for the surge MOM category.
9. Create the Hazus study region, load the categorical depth grid, and perform the analysis.
10. Store the results of the analysis in a commonly accessible file for future use.

DRAFT

The Process

Introduction

This SOP will demonstrate the generation of categorical depth grids for the Hancock County, Mississippi area using the corresponding SLOSH MOM shapefile for the New Orleans basin (MS6).

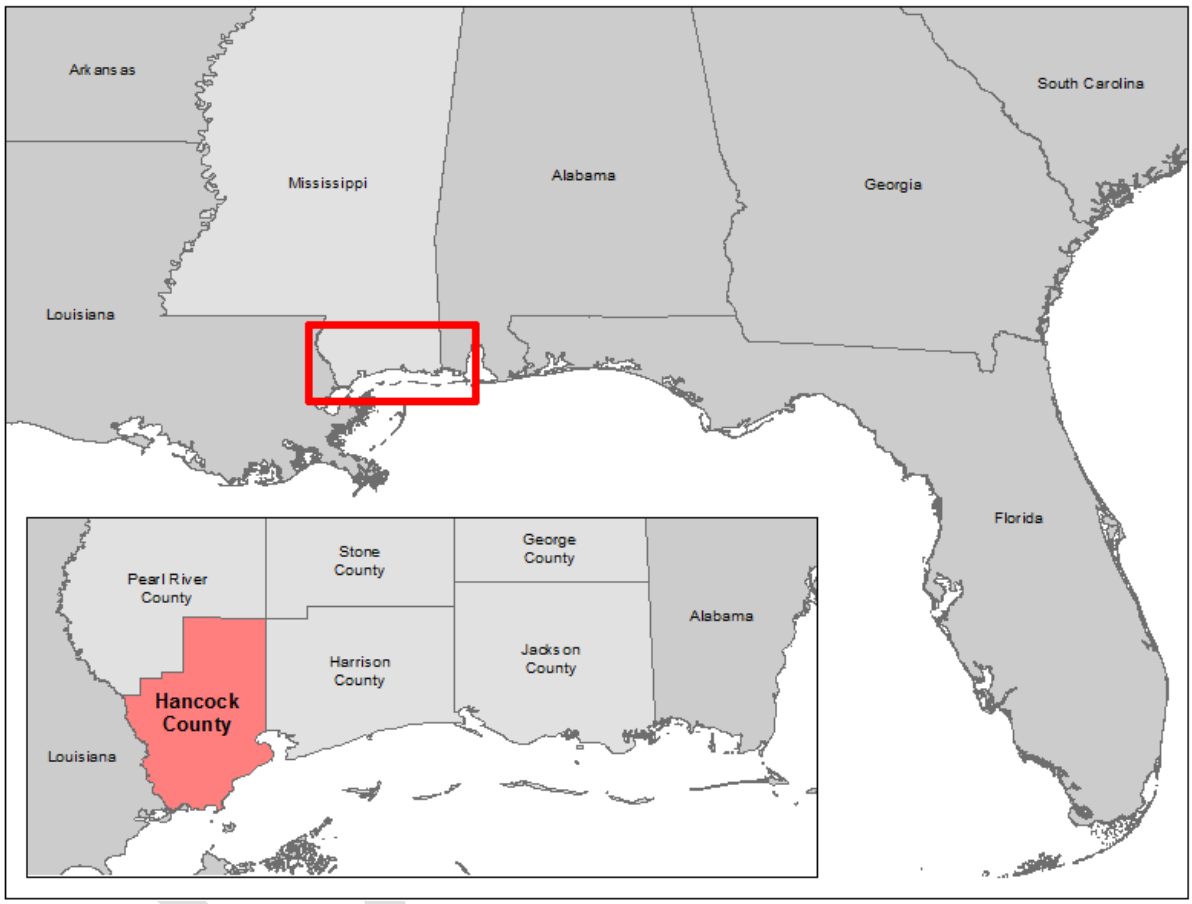


Figure 5. Study area for SOP demonstration.

Figure 6, below, depicts the spatial extent of the New Orleans SLOSH basin (hereinafter MS6). As can be seen, the basin shapefile includes areas of water and land. The smallest grid cell resolution is overland and the largest over water to produce more accurate estimates of overland surge as expected from polar coordinate systems (this is also intended to ease the computational load). It should be noted that many areas in the MOM shapefile include null values or areas where no surge is predicted. Null values are listed in the attribute table as "99.9" for each category MOM**. It is important to exclude null values in this process.**

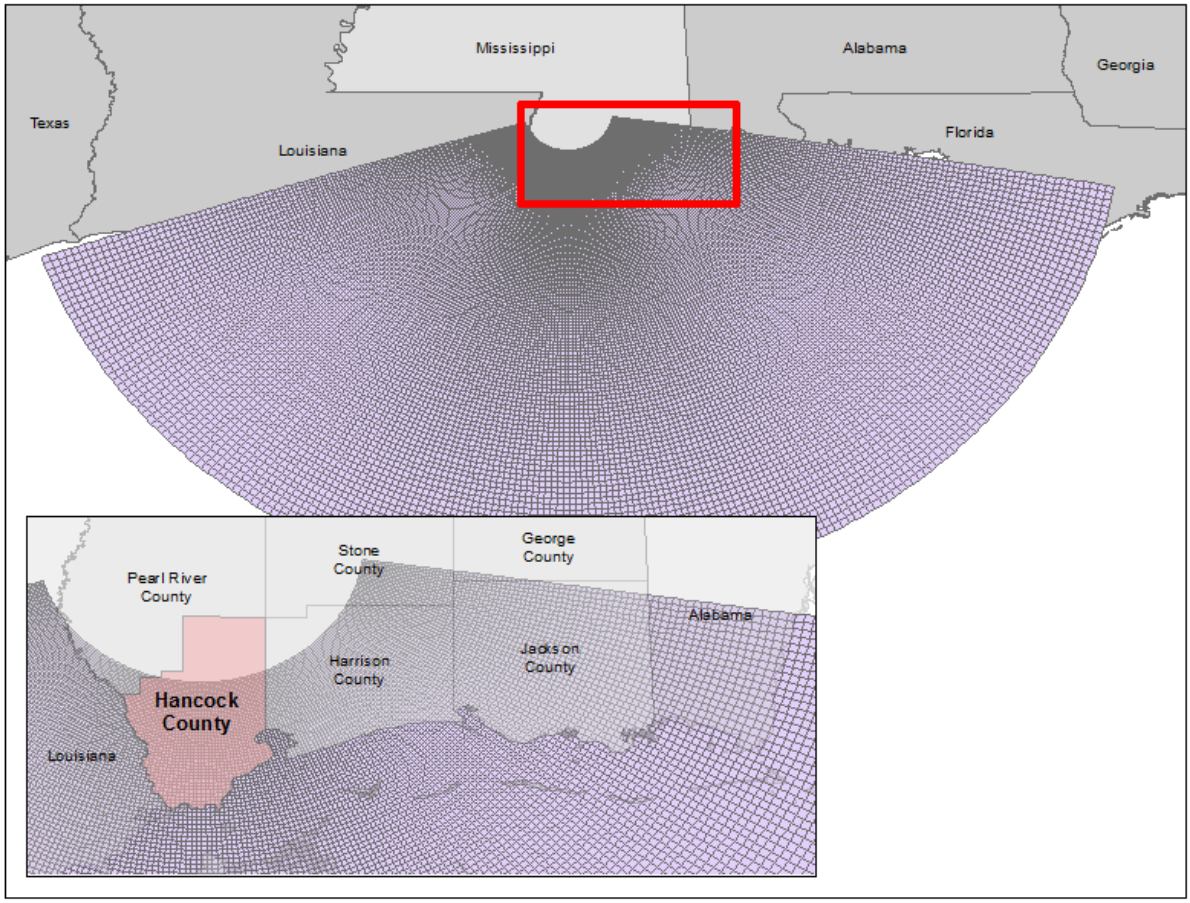


Figure 6. New Orleans SLOSH basin shapefile showing spatial coverage of all basin grid cells.

The attribute table for each MOM shapefile contains the maximum surge values for each hurricane category, including low, mean, and high water depth estimates produced at each MOM grid cell. Since we are interested in the maximum values only, be sure to use the correct attribute for the category MOM you intend to model. **This SOP will produce a depth grid for a category 1 MOM in the MS6 basin. Thus, we will use the C1_HIGH attribute, which corresponds to the maximum surge depth predicted for Category 1 hurricanes.**

Table

ms6mom

FID	Shape *	Poly_id	i_index	j_index	c0_mean	c0_high	c1_mean	c1_high	c2_mean	c2_high	c3_mean	c3_high	c4_mean	c4_high	c5_mean	c5_high
1714	Polygon	92- 42	92	42	99.9	99.9	99.9	-5.3	4.5	7.3	9.3	12	14.9	17.2	19.7	22.3
1696	Polygon	91- 42	91	42	99.9	99.9	99.9	-5.2	4.6	7.6	9.9	12.3	15.1	17.4	20.1	22.6
1733	Polygon	93- 42	93	42	99.9	99.9	99.9	-5	4.5	7	8.9	11.7	14.6	17	19.4	22
1733	Polygon	93- 43	93	43	99.9	99.9	99.9	-2.5	4.4	7	8.7	11.7	14.4	16.8	19.2	21.9
1604	Polygon	86- 65	86	65	99.9	99.9	99.9	1.3	15.1	15.4	18.3	18	18.9	19.3	21.4	22.2
1585	Polygon	85- 64	85	64	99.9	99.9	99.9	1.4	15.1	15.4	18.1	18.7	20.6	20.2	22.4	22.1
1585	Polygon	85- 65	85	65	99.9	99.9	99.9	1.4	15	15.3	17.6	18	19	19.1	21	21.6
8334	Polygon	45- 63	45	63	99.9	2	99.9	2	10.4	11.6	14.1	15.4	19	20.4	23.5	25.1
1566	Polygon	84- 60	84	60	99.9	99.9	99.9	2	7.2	10.2	11	14.9	18.2	19.7	20.5	21
1585	Polygon	85- 60	85	60	99.9	99.9	99.9	2	7.2	10.2	11.1	14.9	17.8	19.3	20.4	20.9
2033	Polygon	109- 32	109	32	99.9	99.9	99.9	2	8.4	10.4	12.9	14.6	16.8	18	19.5	21.3
2070	Polygon	111- 29	111	29	99.9	99.9	99.9	2	7.3	8.8	11.4	13.6	15.9	17.4	19.1	20.6
2071	Polygon	111- 32	111	32	99.9	99.9	99.9	2	7.4	9.4	11.8	13.6	15.8	17.2	18.5	20.7
2331	Polygon	124-188	124	188	0	2	0	2	0	2	0	2	0	2	0	2
2669	Polygon	142-188	142	188	0	2	0	2	0	2	0	2	0	2	0	2
2688	Polygon	143-188	143	188	0	2	0	2	0	2	0	2	0	2	0	2
2707	Polygon	144-188	144	188	0	2	0	2	0	2	0	2	0	2	0	2
2725	Polygon	145-188	145	188	0	2	0	2	0	2	0	2	0	2	0	2
3270	Polygon	174-180	174	180	0	2	0	2	0	2	0	2	0	2	0	2
3270	Polygon	174-181	174	181	0	2	0	2	0	2	0	2.5	0.6	3.6	1.6	5
1284	Polygon	69- 58	69	58	0	2	0.1	2.1	0.2	2.2	13.5	14.3	17.4	19.5	21.6	22.2
1603	Polygon	86- 60	86	60	99.9	99.9	99.9	2.1	7.1	10.2	11.6	14.9	16.4	18.7	19.6	21.1
1731	Polygon	93- 23	93	23	99.9	2	99.9	2.1	9.4	12.7	17.8	19.9	24.3	25.9	30.6	32.1
1731	Polygon	93- 24	93	24	99.9	2	99.9	2.1	9.4	12.6	17.8	19.9	24.4	26	30.6	32.3

0 (0 out of 32712 Selected)

ms6mom

Figure 7. Attribute table for category 1 MOM in the MS6 basin.

NOTE: some SLOSH basins will have the category MOM specifically attributed. Be sure to review the attribute table for the correct column. An example is show in Figure 8 for the Biloxi/MS-Gulf Coast basin.

Table

bixmom

FID	Shape	POLY_ID___	I_INDEX___	J_INDEX___	C1_S05___	C1_S15___	C1_S25___	C1MOM___	C2_S05___	C2_S15___	C2_S25___	C2MOM___	C3_S
9978	Polygon	84-102	84	102	2	99.9	2	2	4.9	7.5	12.6	12.6	
1180	Polygon	100- 24	100	24	2	2	2	2	6.1	2	2	6.1	
1249	Polygon	105-119	105	119	2	2	99.9	2	2	2	2	2	
1394	Polygon	118- 19	118	19	2	99.9	99.9	2	2.5	2	99.9	2.5	
1394	Polygon	118- 20	118	20	2	99.9	99.9	2	3.8	2	2	3.8	
1394	Polygon	118- 21	118	21	2	99.9	99.9	2	4.4	2	2	4.4	
1406	Polygon	119- 20	119	20	2	99.9	99.9	2	2.7	2	2	2.7	
1406	Polygon	119- 21	119	21	2	2	2	2	3.6	2	2	3.6	
1406	Polygon	119- 22	119	22	2	99.9	99.9	2	4.3	2.3	99.9	4.3	
1318	Polygon	12- 10	12	10	2.1	2.1	2.1	2.1	2.4	3.7	5.1	5.1	
1433	Polygon	13- 6	13	6	2	2.1	2.1	2.1	2.1	3.3	4	4	
1434	Polygon	13- 7	13	7	2.1	2.1	2.1	2.1	2.2	3.4	4.2	4.2	
1435	Polygon	13- 8	13	8	2.1	2.1	2.1	2.1	2.3	3.4	4.4	4.4	
9859	Polygon	83-102	83	102	2.1	99.9	2	2.1	4.9	7.7	12.2	12.2	
1319	Polygon	12- 11	12	11	2.2	2.2	2.2	2.2	2.5	3.8	5.3	5.3	
1432	Polygon	13- 5	13	5	2	2.1	2.2	2.2	2.2	3.3	3.9	3.9	
1436	Polygon	13- 9	13	9	2.2	2.2	2.2	2.2	2.4	3.5	4.6	4.6	
1437	Polygon	13- 10	13	10	2.2	2.2	2.2	2.2	2.4	3.6	4.8	4.8	
1550	Polygon	14- 4	14	4	2.1	2.2	2.2	2.2	2.4	3.3	3.9	3.9	
1551	Polygon	14- 5	14	5	2.1	2.2	2.2	2.2	2.3	3.3	3.9	3.9	
848	Polygon	8- 16	8	16	2.2	2.2	2.3	2.3	2.5	5.3	7.3	7.3	
849	Polygon	8- 17	8	17	2.3	2.3	2.3	2.3	2.6	5.4	7.4	7.4	
850	Polygon	8- 18	8	18	2.3	2.3	2.3	2.3	2.7	5.5	7.5	7.5	

0 (0 out of 14161 Selected)

bixmom

Figure 8. Biloxi/MS-Gulf Coast SLOSH basin with specifically attributed MOM category.

Step 1: Convert SLOSH MOM Grids to Points

A. Load into ArcMap a county(s) boundary shapefile (for reference) and the corresponding SLOSH basin. Zoom to the county (by right-clicking on the layer in the Table of Contents and choosing Zoom to Layer). This example uses the county-scale political boundaries shapefile from the National Atlas (NAD83) and the MS6 basin.

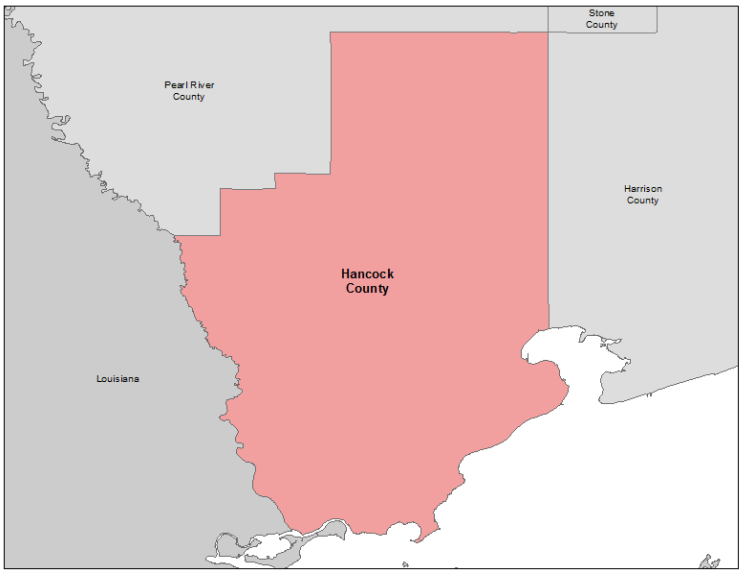


Figure 9. Study area for the SOP.

Note the complete coverage of the SLOSH basin over the coastal area of the county (Figure 10). The null values must be removed.

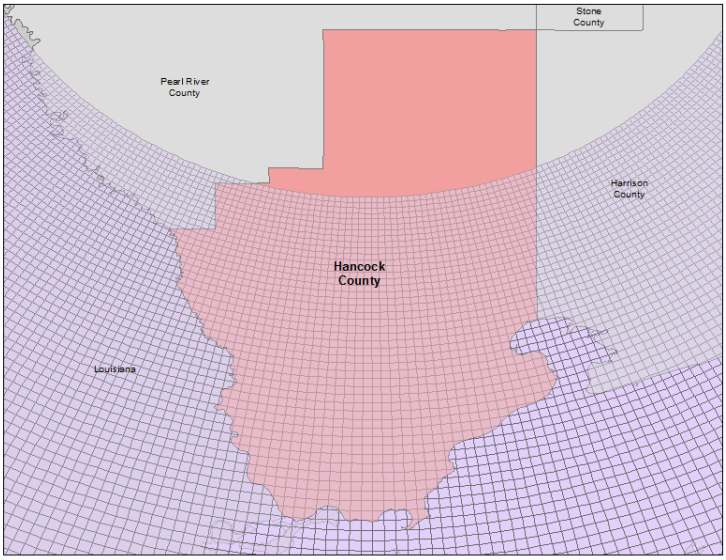


Figure 10. MS6 basin overlaying the study area county.

B. It is not time to use the ET GeoWizards to extract centroid points from the vector polygons which make up the MOM shapefile. Assuming this tool is properly installed (see Appendix A for help), click on the ET GeoWizards tool to start it, click on the convert tab, then select polygon to point per Figure 11 below.

Next, click on the GO, button, then choose the SLOSH MOM layer from the drop-down list (in this case it is called "ms6mom" – Figure 12). You will need to specify the outpoint shapefile next "ms6mom_pts". Click Next

Last, specify the output conversion option as "centers" (i.e. polygon centroids) and then click finish to run the tool as seen in Figure 13. The process will take a few minutes to complete, and the resultant point shapefile will be automatically loaded into ArcMap.

If completed correctly, you should have a point shapefile similar to Figure 14.

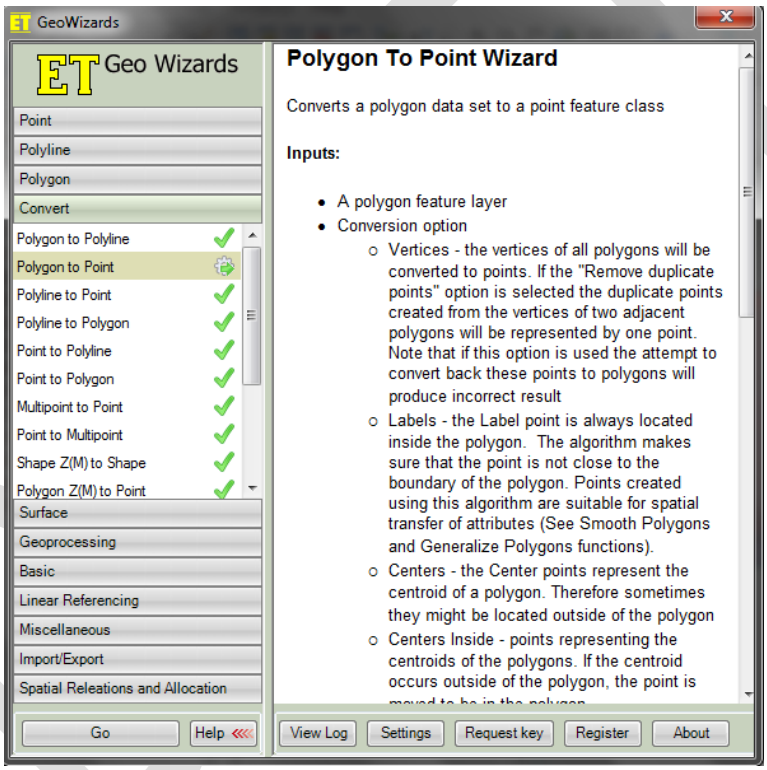


Figure 11. This option in ET GeoWizards converts vector polygons to points.

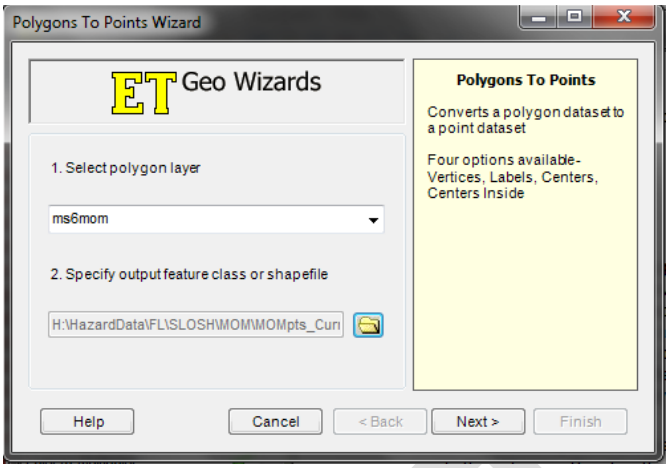


Figure 12. Choose the polygon layer to convert to points as well as an output location and file name.

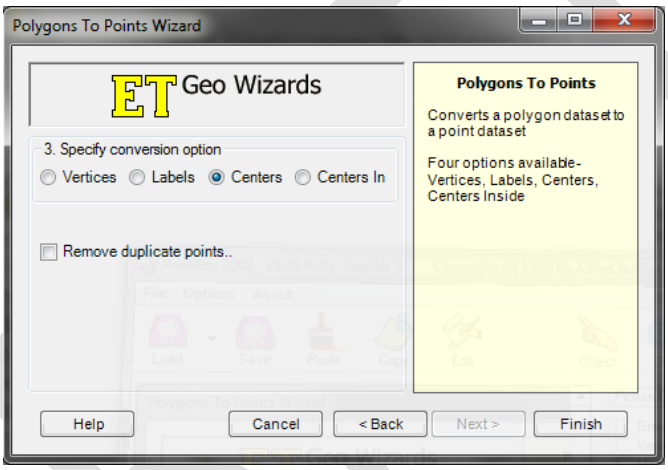


Figure 13.Select "centers" to extract the polygon centroids.

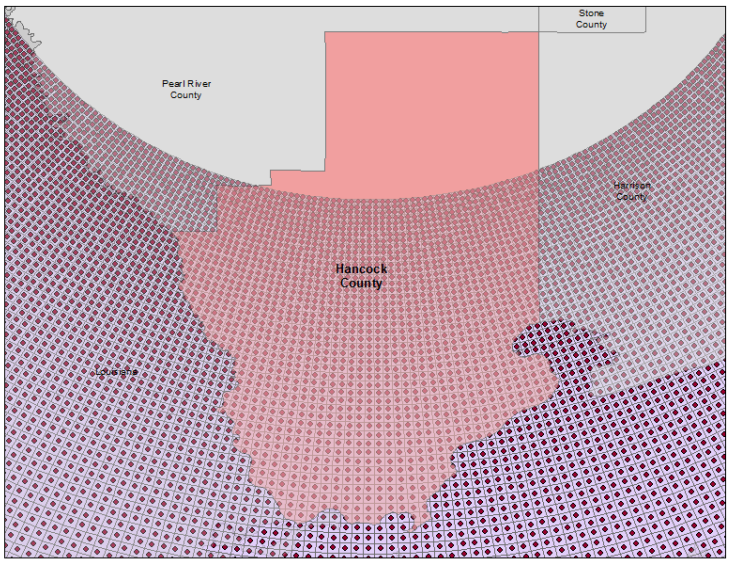


Figure 14. Point shapefile for the MS6 SLOSH basin.

C. Turn off the basin polygons layers, then remove the category 1 null values by right-clicking on the basin layer in the table of contents view and choosing properties. Navigate to the definition query tab, click the query building button and enter or build the following query (Figure 15):

"C1_HIGH" < 99.9

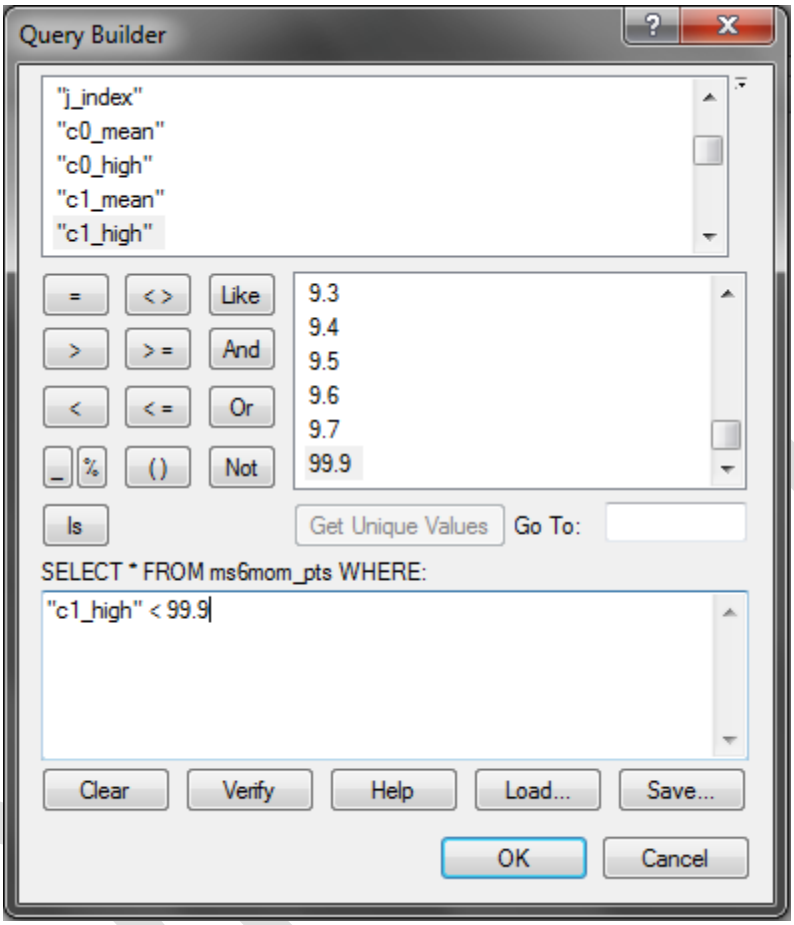


Figure 15. Use the query builder to remove null values from the category MOM.

Of course, substituting the appropriate field for "C1_HIGH" will give you the surge height values for whichever category MOM you intend to map. If you correctly applied the above definition query, you should see the following coverage:

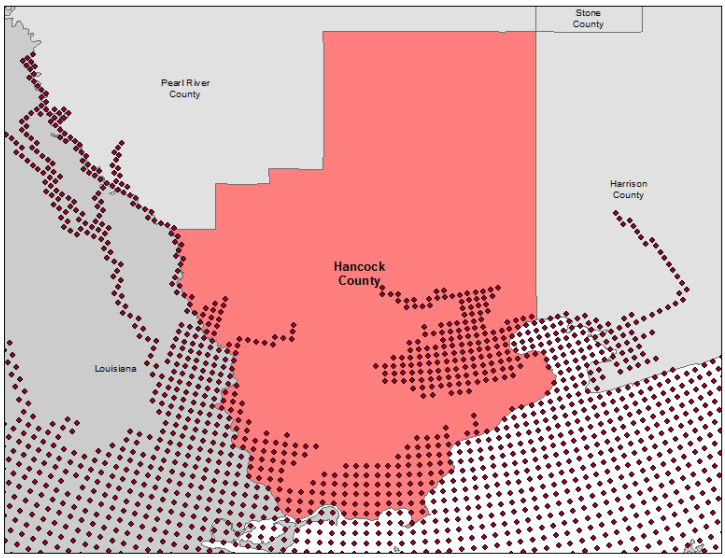


Figure 16. Category 1 MOM null values are removed in this coverage.

NOTE: You are removing null values from the entire basin shapefile associated with the category 1 MOM. Removing the unnecessary points will be demonstrated in Step D.

D. This step removes the unnecessary points (i.e. points to far from the study area to effect the surface interpolation carried out). Selecting only the necessary points for interpolation will cause the depth grid file to be smaller in physical size (disk space) and spatial extent, allowing for the whole process to run in a timely manner. To do this, start by opening the Selection Menu and click "Select by Location". In the Select by Location window, under the "Selection method" drop down menu chose, select features from (this should be the default option). Check the SLOSH points shapefile under Target layers(s), select the county boundary shapefile under Source layer, and the Spatial selection method should be set to Target layer(s) features intersect the Source layer feature (this is the default option). To eliminate the points falling outside a one-mile buffer of the county boundary, check the Apply a search distance box, and type the number 1 and in the units drop down box select miles. This is all shown below in Figure 17.

DRAFT

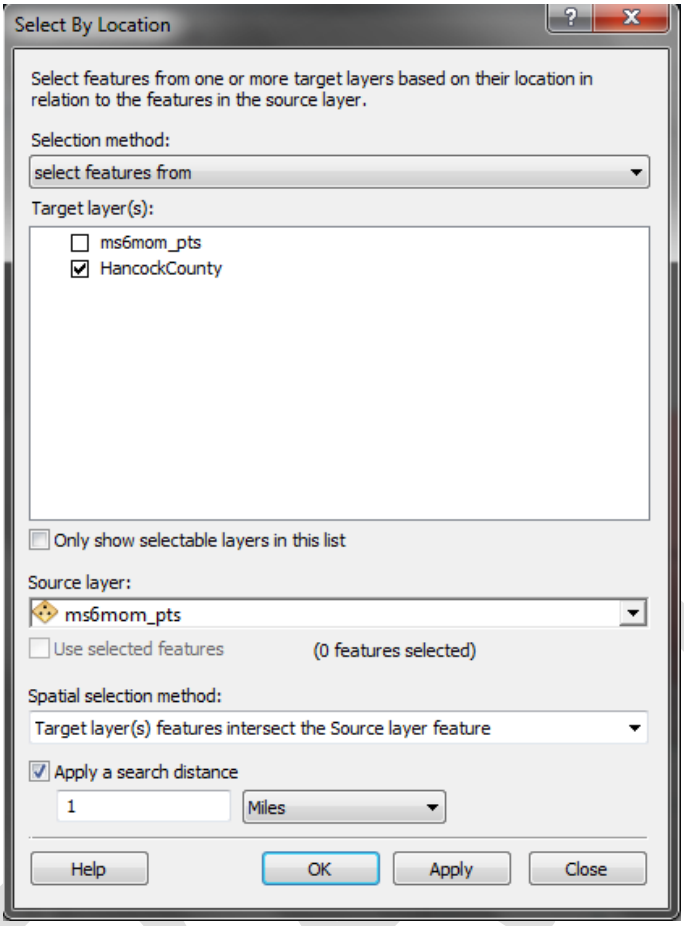


Figure 17. Use the Select by Location tool to create select the points within a one-mile buffer around the study area.

E. The last step in this process is to make the selected points its own layer. To do this right-click on the SLOSH points layer, and choose Selection, and click "Create Layer From Selected Features". This will make a new layer of the points that were selected in Step 1-D above.

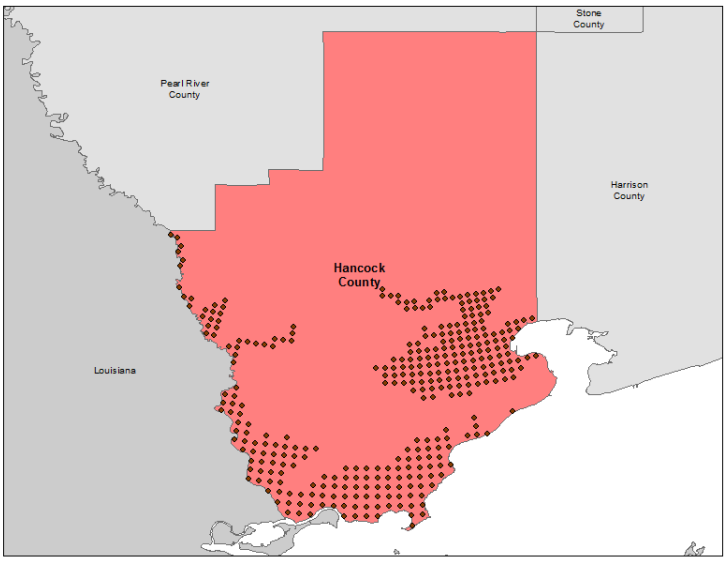


Figure 18. MS6 basin points remaining after selection process using the one-mile buffer.

This completes Step One of the depth grid generation process. If the vertical datum is not in NAVD88, the SLOSH MOM points must be converted from NGVD29 for use with the USGS NED 30- and 10-meter DEMs. The difference in vertical elevations between NAVD88 and NGVD29 (the native SLOSH vertical datum) is slight but must be completed to ensure data accuracy and consistency. Step Two uses NOAA's VERTCON software to carry out the necessary vertical elevation conversion. Please see http://www.ngs.noaa.gov/PC_PROD/VERTCON/ for relevant methodology

NOTE: There are numerous GIS methods to extract the points necessary to create a raster depth grid, including buffering the county shapefile and clipping to the new extent. These methods use more disk space and require more time; however, the GIS process ultimately yields the same results as above.

DRAFT

Step 2: Convert NGVD29 to NAVD88

To maintain consistency and accuracy of the flood depth estimation, the SLOSH data must be converted from NGVD29 to NAVD88 for use with the USGS NED 30-meter elevation data where necessary. In most cases, the difference in elevations will be several inches (based on ellipsoid and gravimetric data). In most cases, SLOSH MOMs data is produced in NAVD88, but some basins are still in NGVD 29. **If the basins vertical datum is NAVD88, you may omit the VERTCON process, and move to Step Three.**

> **NOTE:** Performing this step insures the consistency of vertical data throughout the numerous steps proceeding through the flood hazard analysis. The vertical adjustment, in most cases, is approximately +/- 0.2 feet.

A. Create a unique identifier for each point record in the shapefile you created in Step 1-D. Right-click the layer and choose properties, then open the attribute table. You should have only four fields to work with (FID, C1_HIGH, ET_X, and ET_Y – this can be done by Right-clicking on the layer, going to properties and selecting the Fields tab). Add a field named "Point_ID" by clicking the Table Options button and selecting add field. Make sure the field type is short integer. After creating the field, right-click on the column header for Point_ID and select the field calculator (if you receive a warning message, click ok). Under fields, double-click on FID and then select ok. You will have created a unique identifier for each record using the FID.

   NOTE: This step is necessary because the FID value is not maintained when data from the attribute table is exported from ArcMap to another format. Using the FID data to populate another field, such as Point_ID field above, ensures that a unique identifier is maintained during the export process.

B. While the attribute table is open still, click on the options button and choose export. Choose to export all records, and then choose a file name and location to save the attribute table. Be sure to save the table in dBASE format. It is not necessary to add this table to you ArcMap document.

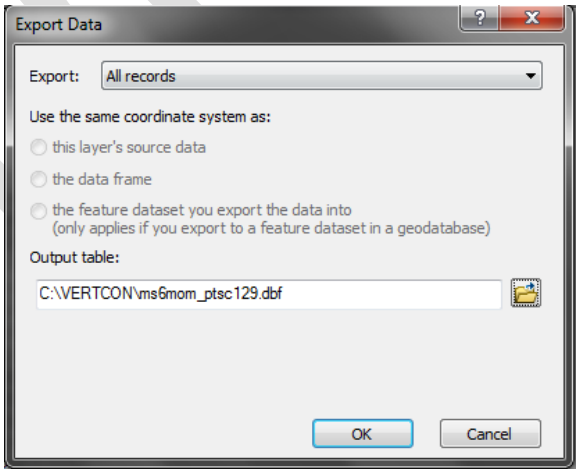


Figure 19. Exporting data to dBASE table.

C. Download the VERTCON software to your computer, and unzip the file locally on the C Drive as recommended by the producers of the VERTCON software.

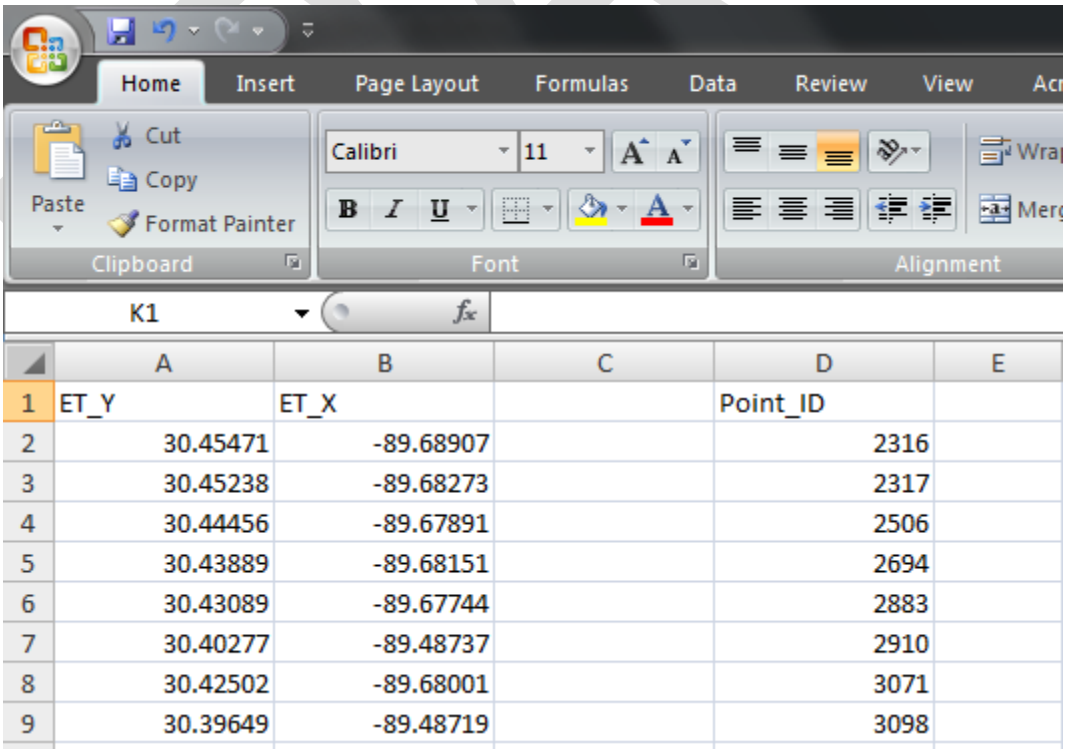
D. You now need to do some manipulation of the data using Microsoft Excel prior to loading the data into VERTCON. Use Excel to open the dBASE file you exported in the previous step. Delete the C1_HIGH column from your file.

NOTE: VERTCON only provides an adjustment based on X and Y coordinates. As such, the only necessary data for the conversion from NGVD29 to NAVD88 are the ET_Y and ET_X fields in the dBASE file.

NOTE: The VERTCON software accepts several input file types, and this process reviews only the method for text file input, which requires coordinate information to be given within the first 32 character spaces (see VERTCON documentation for further notes).

NOTE: The VERTCON transformation software is not to be considered reliable beyond the boundaries of the lower 48 United States (see VERTCON documentation for further notes).

The dBASE file that you exported in Step 2-B above must be formatted such that the Y-coordinate is in column A (in Excel) and the X-coordinate is in column B. Column C will be left empty, and column D will contain the Point ID data.



	A	B	C	D	E
1	ET_Y	ET_X		Point_ID	
2	30.45471	-89.68907		2316	
3	30.45238	-89.68273		2317	
4	30.44456	-89.67891		2506	
5	30.43889	-89.68151		2694	
6	30.43089	-89.67744		2883	
7	30.40277	-89.48737		2910	
8	30.42502	-89.68001		3071	
9	30.39649	-89.48719		3098	

Figure 20. dBase file in Excel.

After your table is reformatted similar to Figure 20 above, right click on the header for column A (ET_Y) and select format cells. Chose “number” from the category list on the left, set the decimal places to 11 if not already set to 11, and under the “negative numbers” choose the second value without a negative sign (in red-see Figure 18 below). Click ok, and ET_Y coordinates should extent to 11 decimal places, and the color should not change. Then repeat this process for column B (ET_X). Once you click ok, the ET_X coordinates should become red indicating they have been reformatted to be negative as well as having 11 decimal places.

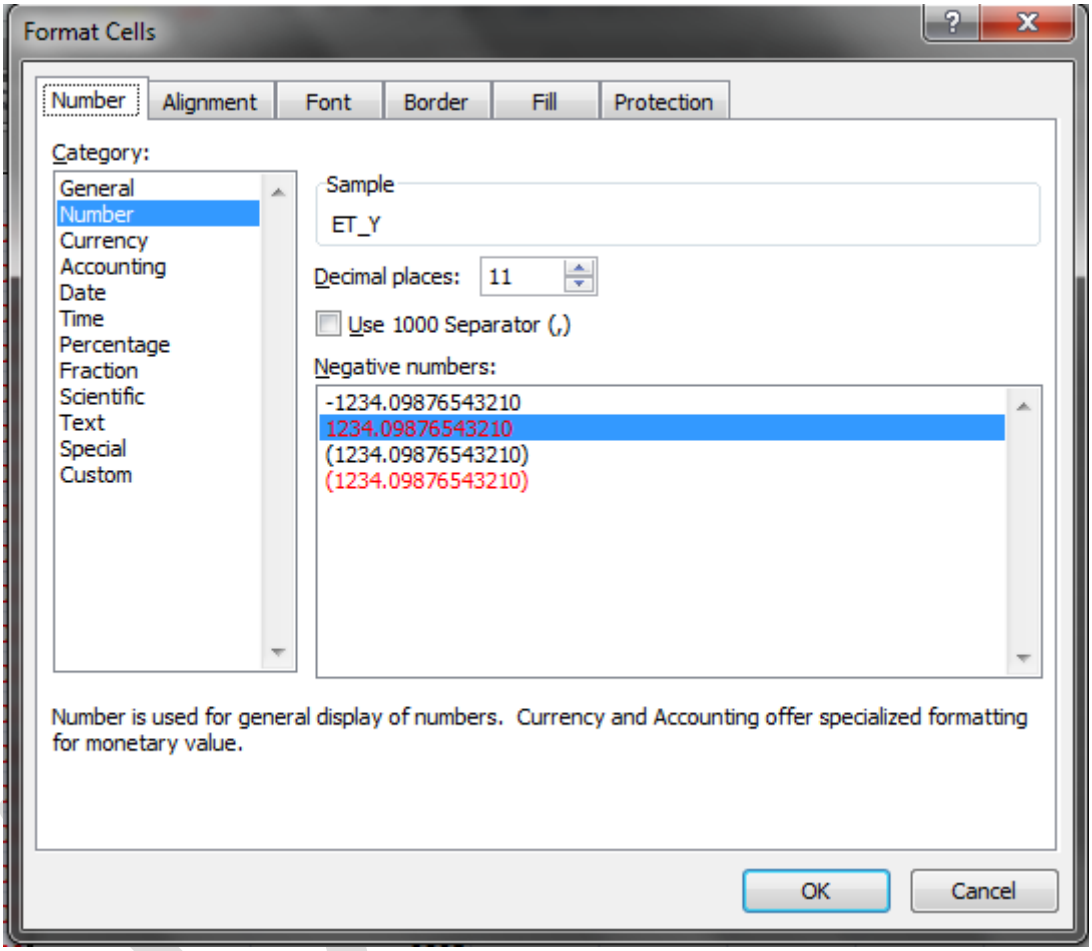
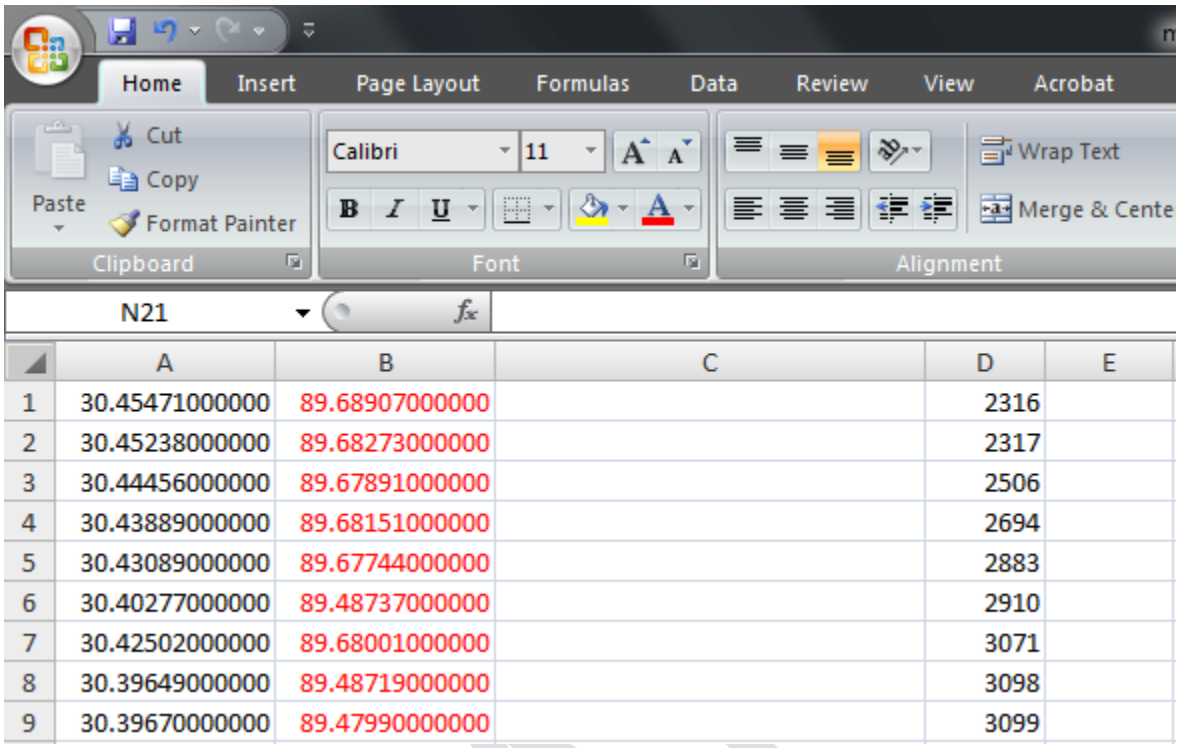


Figure 21. Formatting X and Y cells in Excel.

It is important to make column C in the table wide enough to isolate the first 32 character spaces as coordinates (see VERTCON documentation). It is highly recommended to make this column 215 pixels wide (see Figure 19 below). Delete row 1 (i.e. the field names) by right-clicking on the number 1 and selecting delete row.



	A	B	C	D	E
1	30.45471000000	89.68907000000		2316	
2	30.45238000000	89.68273000000		2317	
3	30.44456000000	89.67891000000		2506	
4	30.43889000000	89.68151000000		2694	
5	30.43089000000	89.67744000000		2883	
6	30.40277000000	89.48737000000		2910	
7	30.42502000000	89.68001000000		3071	
8	30.39649000000	89.48719000000		3098	
9	30.39670000000	89.47990000000		3099	

Figure 22. Make column C wide enough to accommodate the VERTCON elevation difference. It is highly recommended to make column C 215 pixels wide.

When all of the above changes are complete, save the file as a space-delimited text file (i.e. in the Excel File Menu, Save As…, Save as type: Formatted Text (Space Delimited) (*.prn)). The file **must** be saved in the same location as the VERTCON software (C:\VERTCON\ ms6mom_ptsc129.prn).

E. Start VERTCON by navigating to the executable file and opening the application: right-click on the start button, select explore, and then navigate to the VERTCON location (e.g. C:\VERTCON) and double-click the file named vertcon.exe

DRAFT

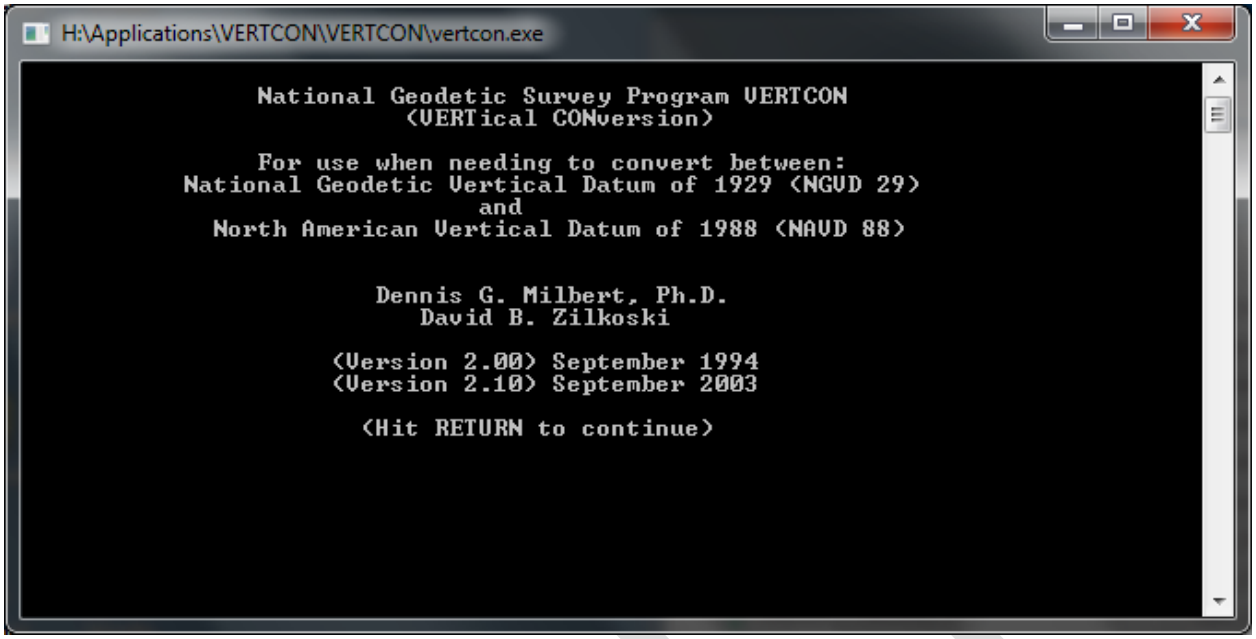


Figure 23. VERTCON startup screen.

Press enter twice, then answer "Y" and hit enter to the question regarding having an input data file. When asked for the file format, type "2" for free format type 2 and hit enter. When asked for the file name, type in the exact name for the space-delimited text file that you saved in the previous step (e.g. if you named the file ms6mom_ptsc129.prn, as suggested in Step 2-D, type "ms6mom_ptsc129.prn" – be sure to include the .prn extension to denote the file format type). The file name used in this example is ms6mom_ptsc129.prn as shown below in Figure 24.

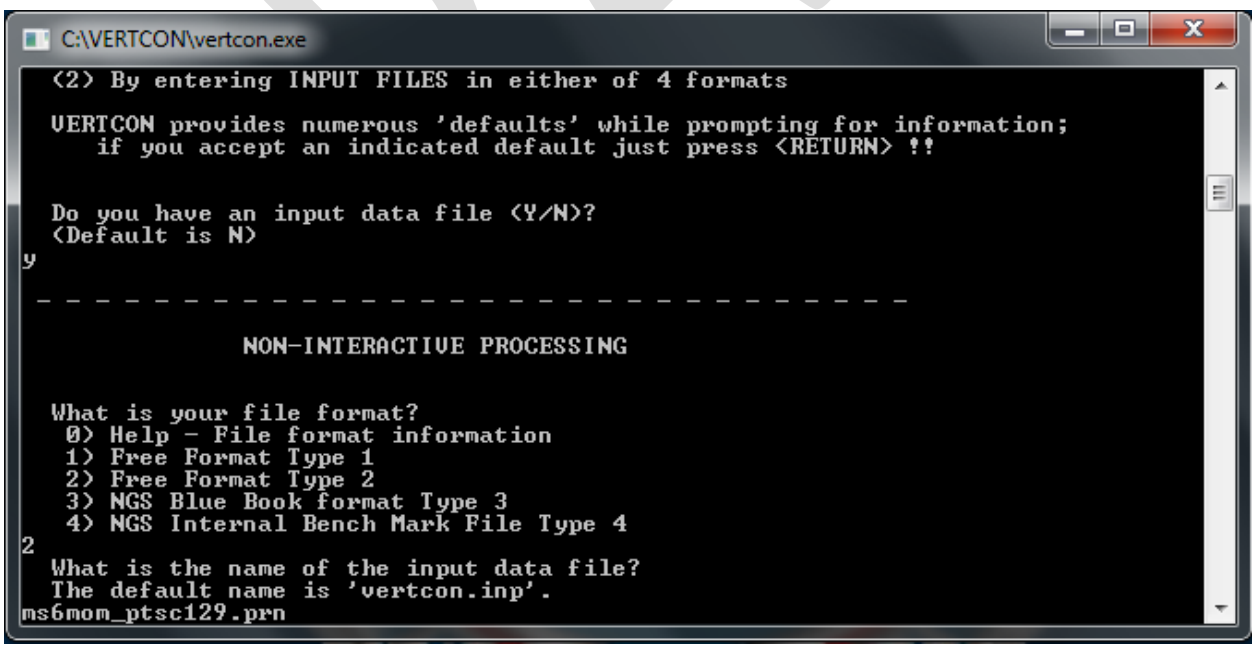


Figure 24. VERTCON startup options.

When asked for VERTCON predictions output, type "N" and hit enter. Next, enter the name of the output file (e.g.ms6mom_ptsc129.out) and hit enter. The VERTCON program will run and

produce a text file by the name you assigned; this file can be found in the same location as the VERTCON software. It is very possible that the output file will not contain any values; repeat this process following each step very closely.

Navigate to the output file and open it with Notepad or WordPad and note that the fourth column of data has been added which includes the vertical adjustment data. Close Notepad or WordPad and open a new Excel spreadsheet. Navigate to and open the output file (you may need to change the file type to text file). The text import wizard should automatically open (Figure 25), if not, highlight column A, navigate to Data, and choose Text to Column.

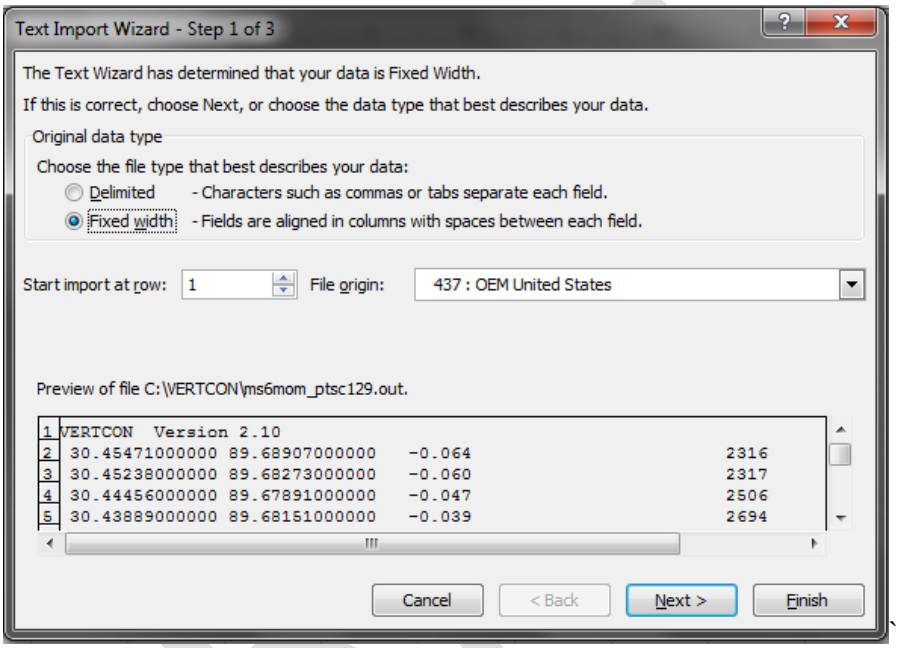


Figure 25. Text file import wizard.

For step 1 of the wizard, leave the defaults as they are and click next. At step 2 of the wizard you may need to adjust the column width – do so; if not, continue to step 3 and finish by clicking next and then finish.

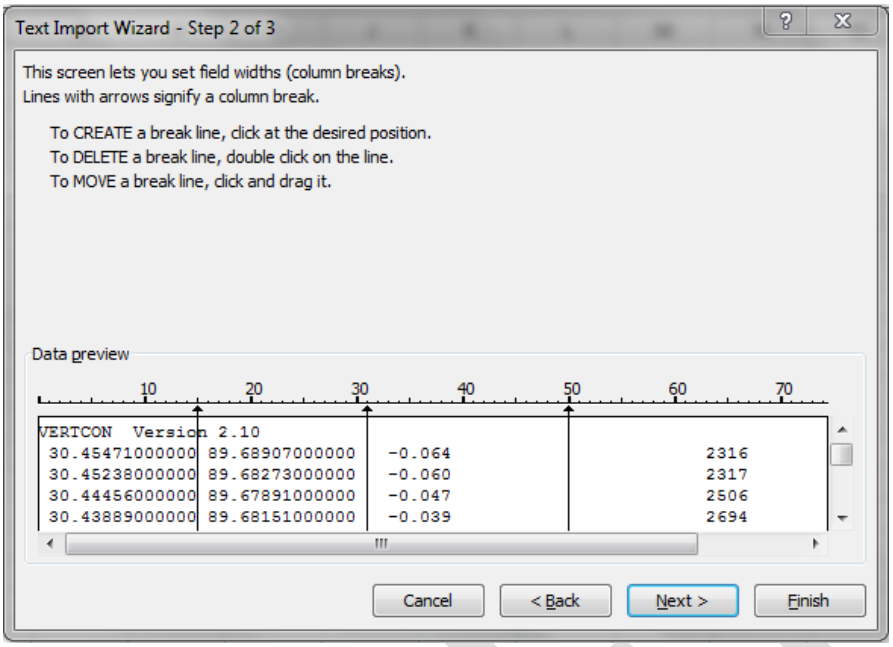
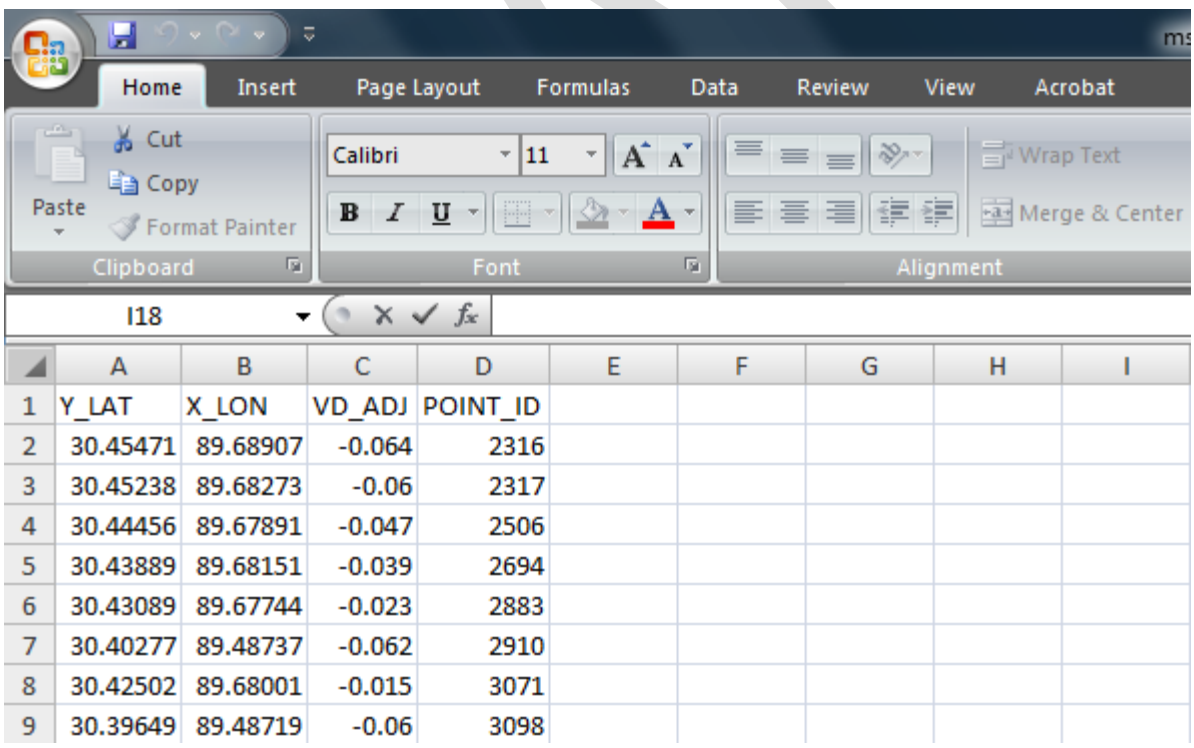


Figure 26. Text file import wizard Step 2.

Once the text file has been imported into Excel, rename the column headers to appropriately represent the fields (see Figure 27).



	A	B	C	D
1	Y_LAT	X_LON	VD_ADJ	POINT_ID
2	30.45471	89.68907	-0.064	2316
3	30.45238	89.68273	-0.06	2317
4	30.44456	89.67891	-0.047	2506
5	30.43889	89.68151	-0.039	2694
6	30.43089	89.67744	-0.023	2883
7	30.40277	89.48737	-0.062	2910
8	30.42502	89.68001	-0.015	3071
9	30.39649	89.48719	-0.06	3098

Figure 27. Change the column headers accordingly.

Upon remaining the fields, save the file as an Excel Workbook (.xlsx) and close Excel.

F. Open the ArcMap document which was used to create the SLOSH point shapefile in Step 1-D and add the Excel worksheet created in Step 2-E above.

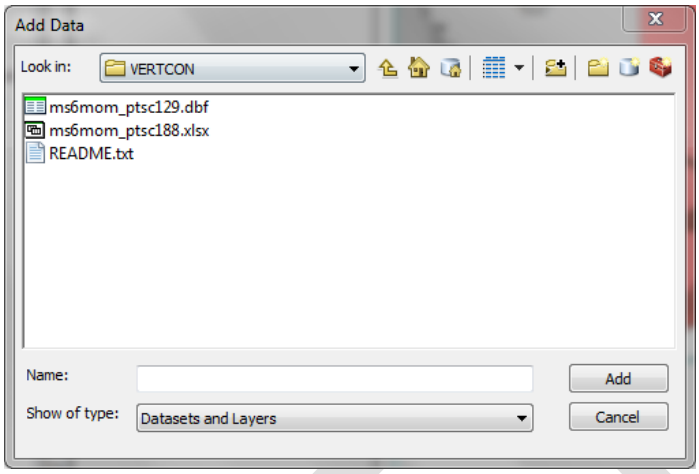


Figure 28. Use the Add Data button to import the Excel file.

Click on the source tab in ArcMap table of contents view, then right click on the Excel file (appearing as a layer) and click open to view the records. This Excel file containing the vertical datum adjustment must be joined to the existing point file created in Step 1-D. Reload this point shapefile if it is not currently in your ArcMap document, then right-click on it, select joins and relates, and chose joins.

In the Join Data dialog box, you will "join attributes from a table" based on 1) the FID field, 2) the Excel worksheet layer, and 3) the Point_ID field (or whatever you named your ID field in Excel). See Figure 29 below for an example. Click ok when the fields are mapped properly.

DRAFT

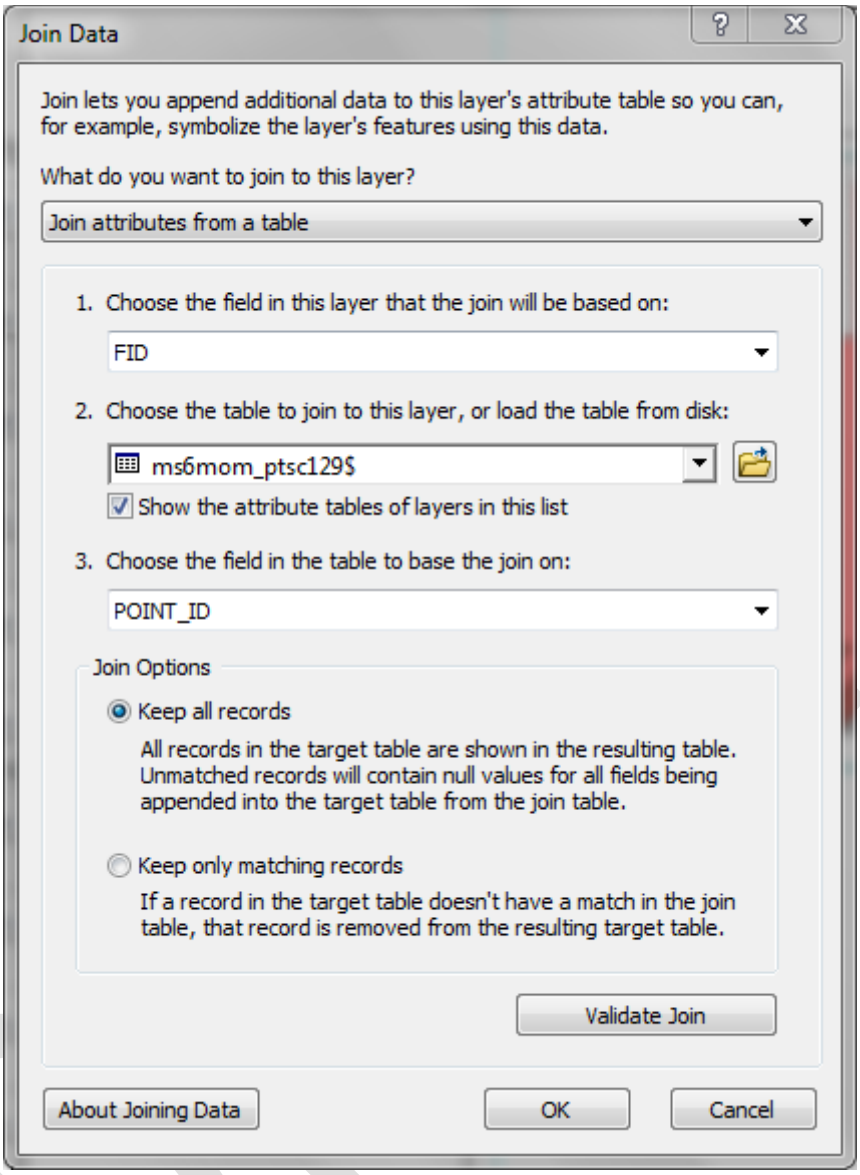


Figure 29. Join the elevation difference file to the SLOSH points layer.

In the table of contents view in ArcMap, right-click on the SLOSH point shapefile, select data, then choose to export data. Naming the output shapefile accordingly (e.g. ms6mom_ptsc1convrt.shp is used in this example). Click "yes" when prompted to add the exported data to your map.

G. Right-click on the exported point shape file in ArcMap, and choose properties, select the display tab, click the clear all button, and then place a checkmark in the boxes for C1_HIGH (or whichever category you are working with) and VD_ADJ. Next, open the attribute table, click on the option button, then select add field. Name this field "VD_ADJ_FT" to correspond with the next calculation, converting the vertical datum adjustment to English feet rather than metric meters, and make its type float.

In the attribute table, right-click on the VD_ADJ_FT field and select the field calculator. In the field calculation, double-click VD_ADJ, then click on the asterisk (*), then punch in 3.2808 (the conversion factor for meters to feet) as show below in Figure 30.

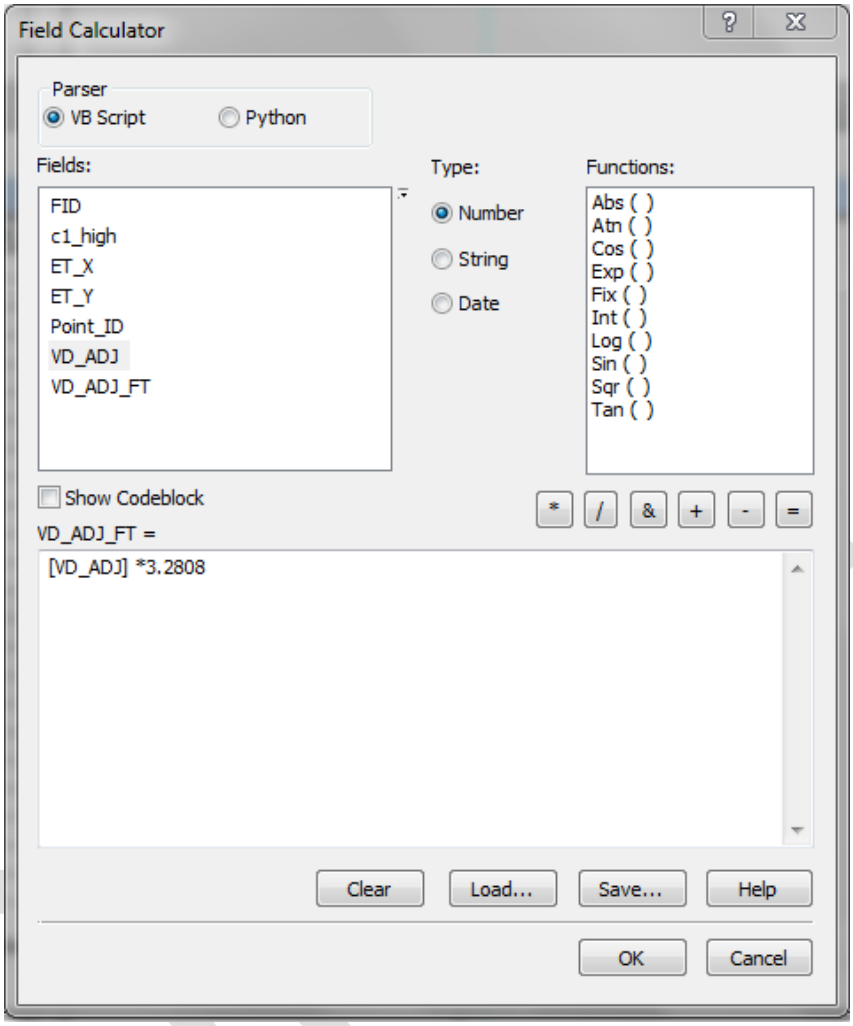


Figure 30. Use the Field Calculator to convert from meters to feet.

The next step is to add the vertical adjustment to the C1_HIGH field. With the attribute table open, click the options button and select add field. Name this field C1_HIGH_88 and make its type float. Next, right-click on the C1_HIGH_88 field and select the field calculator. In the field calculator, double-click the C1_HIGH field, then click the plus (+) button, and then double-click the VD_ADJ_FT field name and click OK to perform the calculation.

Finally, once you have the final table with the SLOSH values converted from meters to feet, it is important to export the final table to ensure that all changes are saved within the table.

Step 3: Interpolate the Flood Surface

After completing Step 2 above, use the Inverse Distance Weighting (IDW) tool to statistically interpolate the category flood surface, thereby converting the vector points to raster format for use in Hazus.

Start by opening the IDW tool in the spatial analyst toolbox under interpolation and choosing the NAVD88 SLOSH points as the input feature. Next, set the Z-value field to the Category 1 MOMs field (i.e. C1_HIGH if you maintained a field name during Step 2).

For the output raster file name, use a logical name for the category, basin, and county study area (e.g. in this case, the raster is called "ms6idwc1" denoting the MS6 basin, Category 1, and IDW), and set the output cell size to that of a USGS 30-meter DEM (or the cell size of the DEM that you will be using see Figure 31).

Next click on Environments, and set the Output Coordinates and Processing Extent. Both need to be set to match the county boundary shapefile. Then click on Raster Analysis and set the cell size to that of the DEM that will be used (see Figure 31).

NOTE: It is important to set the Processing Extent to that of the county boundary shapefile so that the extent of the interpolated water surface will be available for entire county for subsequent steps.

NOTE: It is good practice to store your output raster in a temporary file directory so that it can be deleted at a later time. The IDW raster will be used to generate the depth grid, and after this is completed in Step 4 below, you will no longer need the IDW raster.

For the output cell size, specify the cell size which matches your DEM. The SOP specifies minimum use of the USGS NED 30-meter DEM for the Coastal Flood Loss Atlas (CFLA), yet use of higher resolution elevation data is encouraged when data and time are available. Be sure to check that the coordinate system is consistent across processes. When using the NAD83 geographic coordinate system (the national standard), the corresponding cell sizes are:

Product	Resolution	Projection	Horizontal Datum	Vertical Datum	Vertical Units	Cell Size
National Elevation Dataset (NED) 1 Arc Second (~30m resolution 1 arc-second (approx. 30m)	1 arc-second (approx. 30m) - Cont. U.S., HI, PR, & VI 2 arc-second (approx. 60m) - AK	Geographic	NAD83 - Cont.U.S., HI, PR, & VI NAD27 - AK	NAVD88 - Cont. U.S., HI, PR, & VI NGVD29 - AK	Meters	0.00027778
National Elevation Dataset (NED) 1/3 Arc Second (~10m resolution)	1/3 arc-second (approx. 10m) - Conterminous US - Where available (see *The National Map* Seamless Server for current coverage) and Hawaii	Geographic	NAD83	NAVD88	Meters	0.000092593
National Elevation Dataset (NED) 1/9 Arc Second (approx. 3m)	1/9 arc-second (approx. 3m) Cont. U.S. - Where available (see *The National Map* Seamless Server for current coverage)	Geographic	NAD83	NAVD88	Meters	0.000031

Figure 31. Spatial resolutions and raster cell sizes. (Source: USGS, seamless.usgs.gov)

DEM Resolution	Cell Size
30-meter	0.00027778
10-meter	0.000092593
~3-meter	0.000031

If you have your DEM loaded, click the environments button and manually force consistency in coordinate systems and raster resolution in the options for general settings and raster analysis settings.

After entering the appropriate cell size, leave all other options as default (i.e. power of 2 and variable search radius of 12 points) and click OK to run the tool. Depending on how many points are in the basin and the specified raster resolution, the process could take some time to complete (e.g. 30-meter can take a few minutes, and 3-meter or LiDAR data could take several hours).

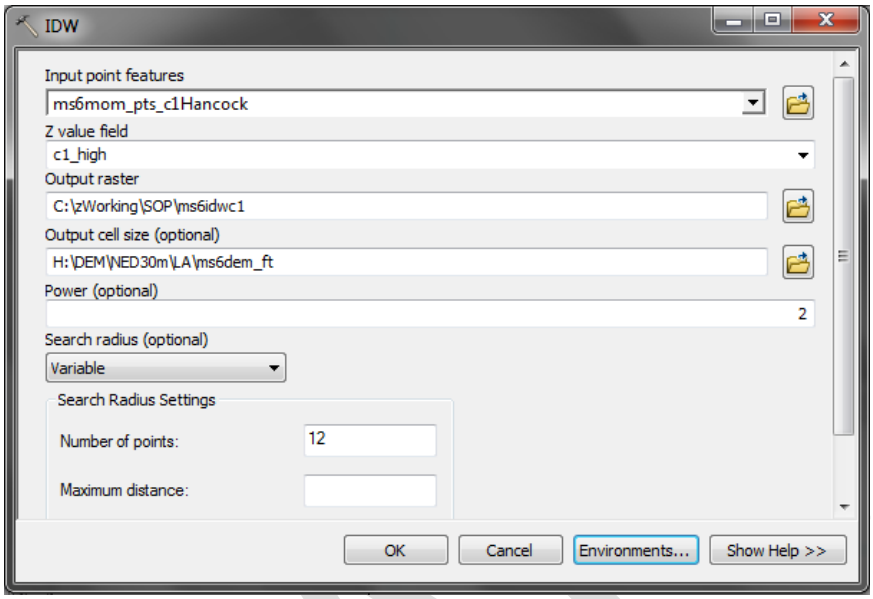


Figure 32. Settings for the IDW tool.

When the IDW process is complete, you should get a surface which looks something like this:

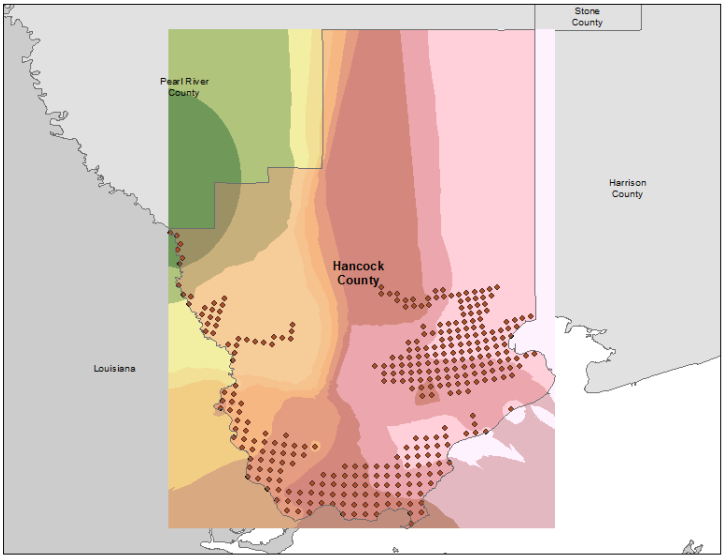


Figure 33. Flood surface generated from the IDW interpolation.

Step 4: Hazus Depth Grid Tool

The Hazus Depth Gird Tool was developed in Model Builder to preserve and make constant the process of generating a "user-supplied depth grid: for use with the Coastal Flood Module.

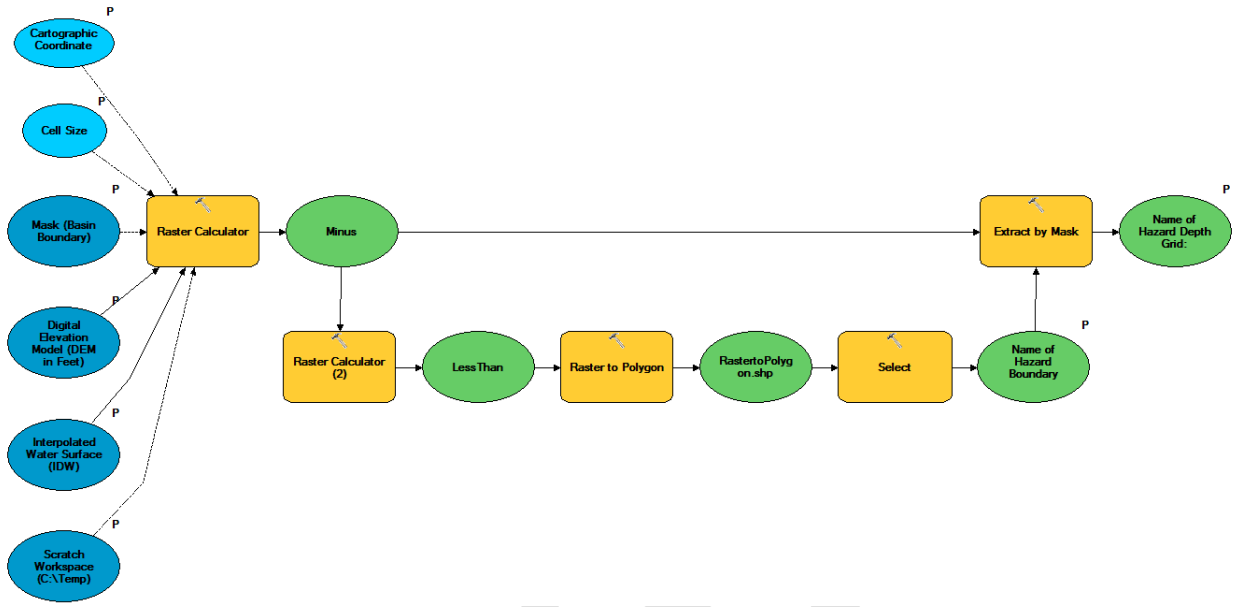


Figure 34. The Hazus Depth Grid Tool as seen from Model Builder.

Start this step by opening the Hazus 2.0 Toolbox and running the "Create Hazus Depth Grid" tool. You will need to specify the following inputs as noted in Figure 35.

- Interpolated flood surface raster (from Step 3)
- Study area DEM (which will remove areas not inundated)
- Analysis cell size (choose "Same as Layer X" from the drop-down list, and select the IDW layer – e.g. Same as Layer "ms6idwc1")
- Coordinate system (again, choose the "Same as Layer X" as above)
- Defined scratch workspace (C:/Temp)
- Mask (County boundary file)
- The hazard boundary polygon shapefile (this vector file depicts the spatial coverage of overland surge)
- The depth gird and boundary shapefile name (limited to 13 characters)

NOTE: Due to technical changes in the temporary working storage location and raster format settings within the scratch workspace, an update to the model was necessary. The update also incorporates the masking parameter into the GUI, however it is still recommended that these parameters continually be set under the Environments button.

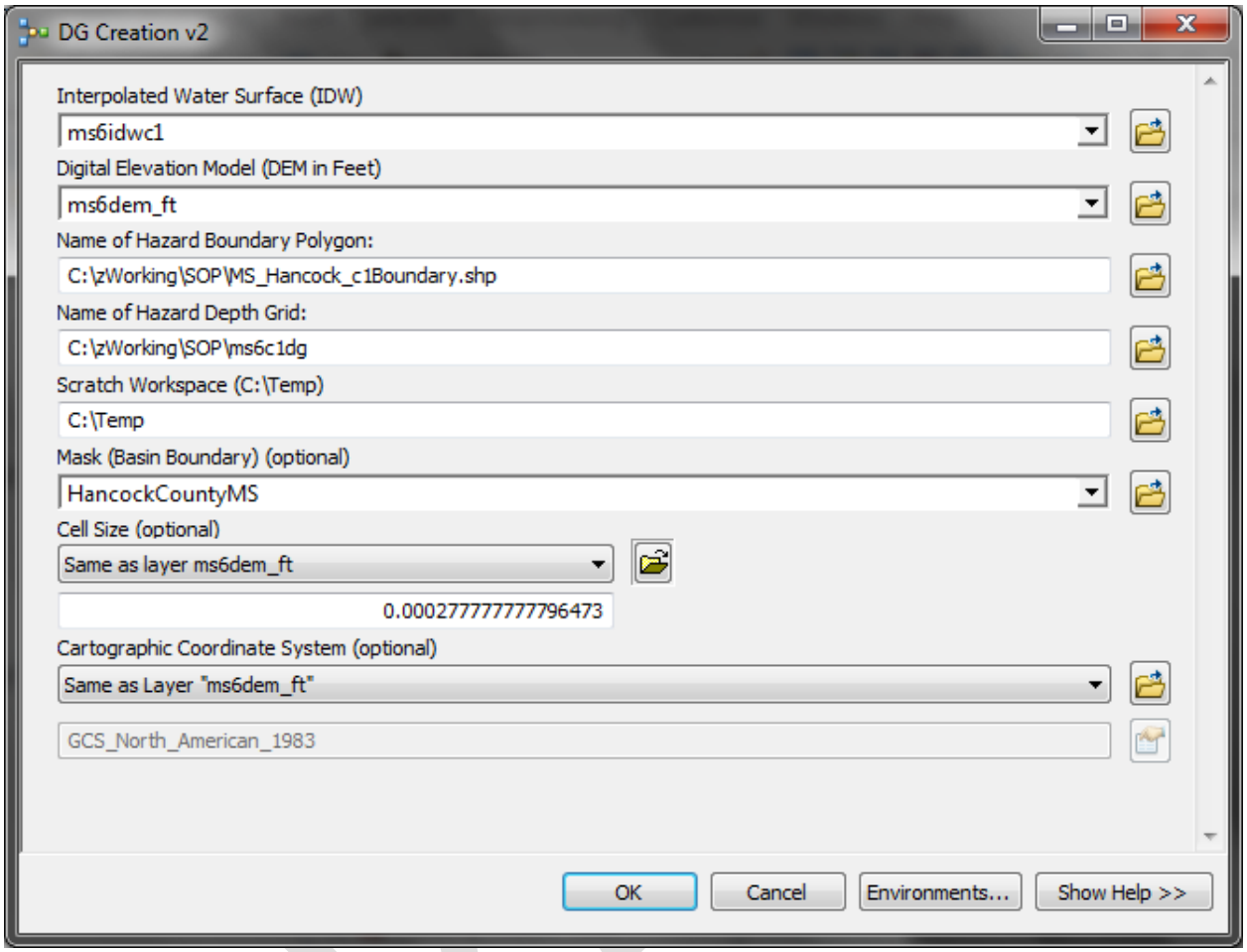


Figure 35. Inputs necessary to run the Hazus Depth Grid Tool.

Under the Environments tab the following inputs will need to be specified:

- Output Coordinates (choose "Same as Layer X" from the drop-down list, and select the county boundary layer)
- Raster Analysis (choose "Same as Layer X" from the drop-down list, and select the IDW layer – e.g. Same as Layer "ms6idwc1") and (set the mask to the county boundary shapefile)

It is recommended to use a common file naming convention for the boundary polygons and depth grids (Figure 15). Also, consider how to store the vector and raster files on a hard desk or server location. As with Step 3 above, the time required to generate the depth grid is relative to the raster resolution. Generating a 30-meter depth grid could take as little time as a few minutes, where a LiDAR resolution depth grid at approximately 3-meters could take several hours of processing time. When the tool finishes successfully with the correct input parameters, you should have a depth grid usable in Hazus 2.0 as well as a vector polygon shapefile representing the spatial extent of the overland floodwater associated with the SLOSH MOM category (depending on resolution, this vector file is the same extent of flood used for hazard delineation and evacuation planning in HES). See Figure 36, 37, and 38 for examples o the resultant depth grids and coverage polygons generated from the Hazus Depth Grid Tool.

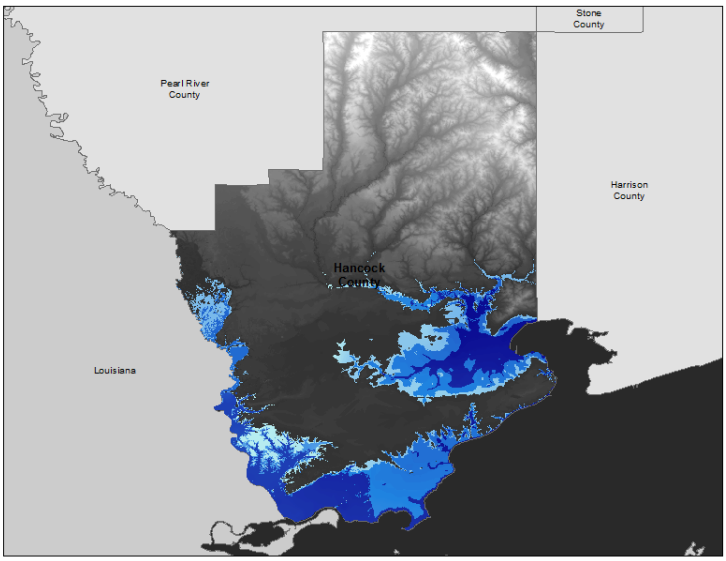


Figure 36. The Hazus Depth Grid Tool produces a raster which and be imported directly into Hazus 2.0 and used for refined analysis at level 2.

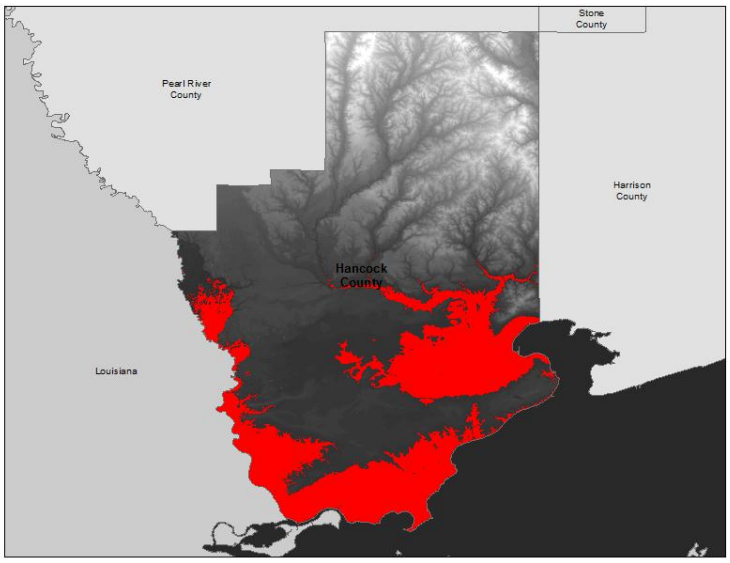


Figure 37. The vector polygon produced by the Depth Gird Tool is roughly the same file used for the HES. These vector polygons can be overlaid for numerous maps analyses and visual displays. The Category 1 SLOSH MOM points overlay the polygon.

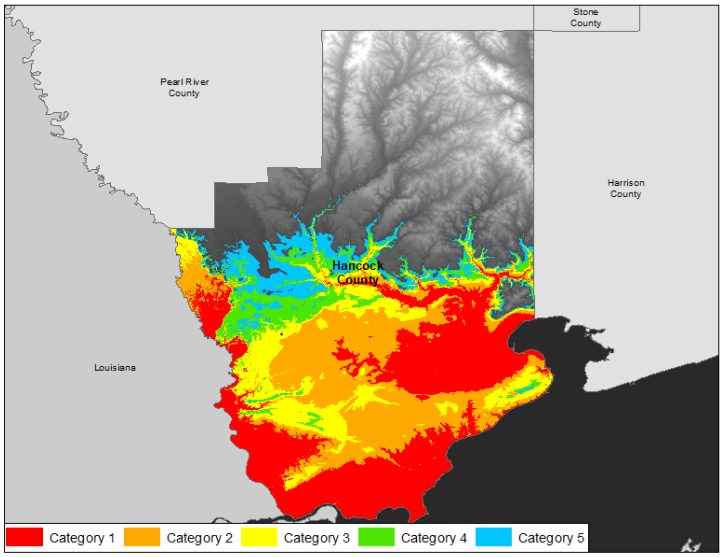


Figure 38. Category 1-5 MOMs for Hancock County, MS generated from the Hazus Depth Grid Tool and the USGS NED 30-meter data.

NOTE: The original Hazus Depth Grid Tool was developed using ArcGIS Model Builder by H. E. Longenecker with the FEMA Region IV Risk Analysis Team. The tool has been updated so that it is compatible with ArcMap 10.0, by the FEMA Region IV Risk Analysis Team, H. E. Longenecker, S. Moses Wilkins, Niclaos Almonor, and Casey Zuzak. The tool is intended for use by all with the development of GIS –users toolbox for inclusion with the future release of the Hazus software. Please contact someone from the FEMA Region IV Risk Analysis Team for a copy of this tool.

NOTE: It is possible to create a depth gird and boundary file for the entire SLOSH basin; however it is a laborious task to individually clip each file to the county boundary (10 clips per county for about 6-15 counties per basin). Appendix C includes a Python Scrip that was created to clip multiple counties at the same time.

DRAFT

Step 5: Import Depth Grid and Analyses

The SOP recommends a standard naming convention for all coastal flood study regions building for the Coastal Flood Loss Atlas (CFLA). That convention is as follows

FL_R4_MS_Hancock Hazard_FEMARegion_State_County

Where:

FL – Designates that the study region is for the Flood Hazard
R4 – Designates that the study region was created for FEMA Region IV
MS – Designates that the study region was created for the state of Mississippi
Hancock – Designates that the study region was created for Hancock County, MS

Using spaces in naming study regions is an unacceptable and unwise practice thanks to the many headaches which can be caused by "broken filenames" (i.e. spaces cause each part of a filename to be read as an individual file). It is a good practice to use the underscore instead of spaces.

A single county-level study region can be used to perform analyses for Category 1 through 5 storm surge MOMs. Once the study region is built, category MOM depth grids can be substituted for the required analyses using the User Supplied Data Wizard.

It is important to adhere to this study region file naming convention for storage of the study region HPR files (Hazus Packaged Region). Upon completion of surge analyses for the SLOSH MOMs, the study regions will be exported to the compressed HPR format and stored on the Region 4 GIS/Hazus server for reference and use in the event of NRCC or RRCC activation for landfalling cyclones.

NOTE: This SOP assumes the study region is already built with the preceding conventions.

A. Open the Hazus study region and under the Hazard menu set the Flood Hazard Type to "Coastal Only" (Figure 39, below). Next, in the Hazard menu, select User Data to open the DEM and Depth Grid Wizard. Under the Depth Grid tab, browse to the location of the depth grid that you want to import, and click select. This will add the user defined depth grid to Hazus for analysis (Figure 40). Then click "Set Parameters" to set the vertical units to feet for the depth grid (Figure 41). Once the depth grid has been loaded and the vertical units set, then click OK, and then Hazus will ask if you want to continue without setting an assign a return period for each depth grid, click Yes.

DRAFT

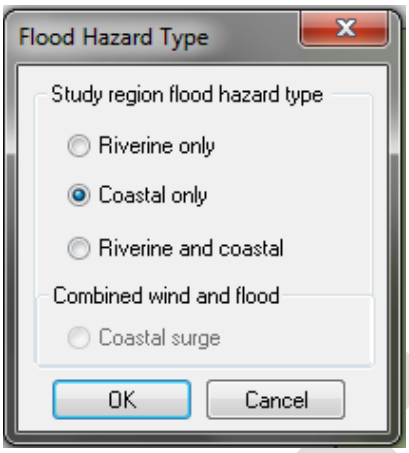


Figure 39. Flood Hazard Type setting.

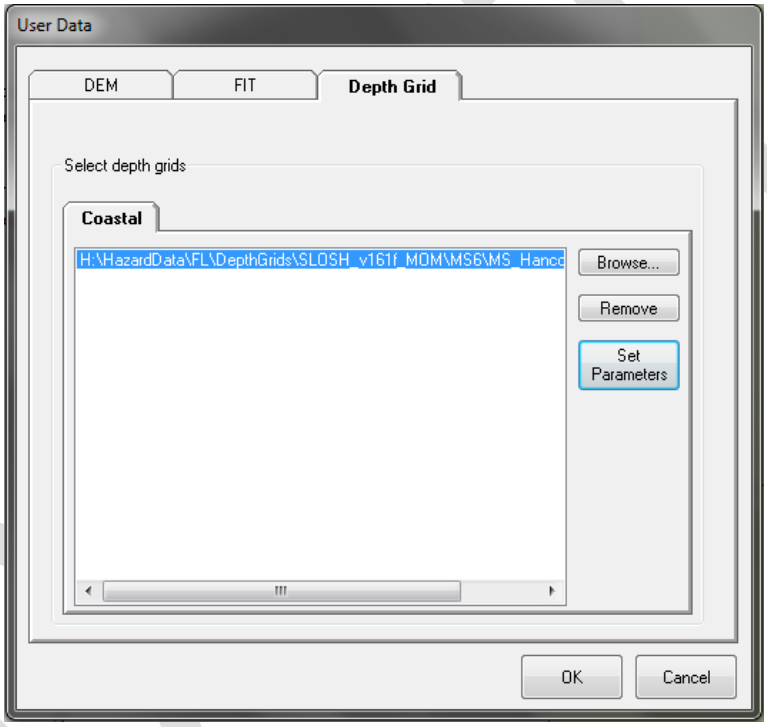


Figure 40. Hazus User Defined Depth Grid interface.

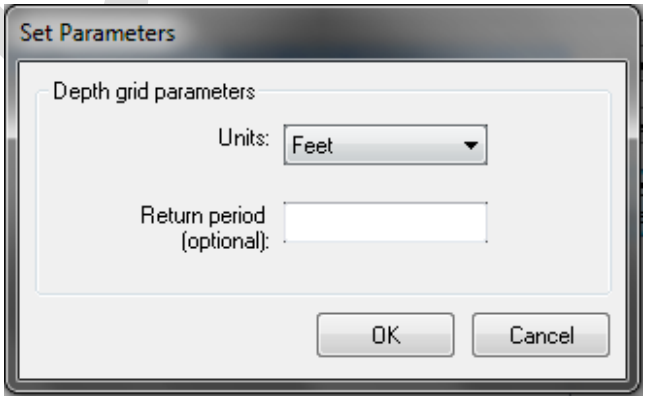


Figure 41. Set Parameters of depth grid to feet.

B. Create a new scenario case by going to the Hazard menu and clicking on Scenario then New. Name the study region accordingly (e.g. basin name, surge category, and county name; see Figure 42 below). Then proceed to select the user defined depth grid supplied in the previous step by click the "user-defined depth grid" radio button option on the new scenario wizard (this should be the default option), then click the plus button next to "add to selection," and then click on the flood extent polygon in the map window. Finalize your selection by pressing the save selection button and finally click OK (see Figure 43 below).

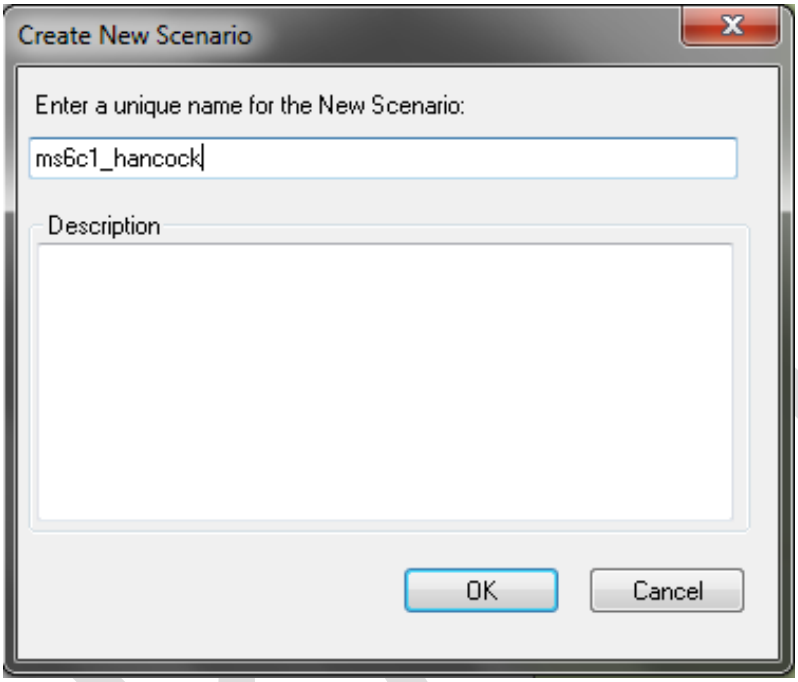


Figure 42. New Study Case Scenario wizard.

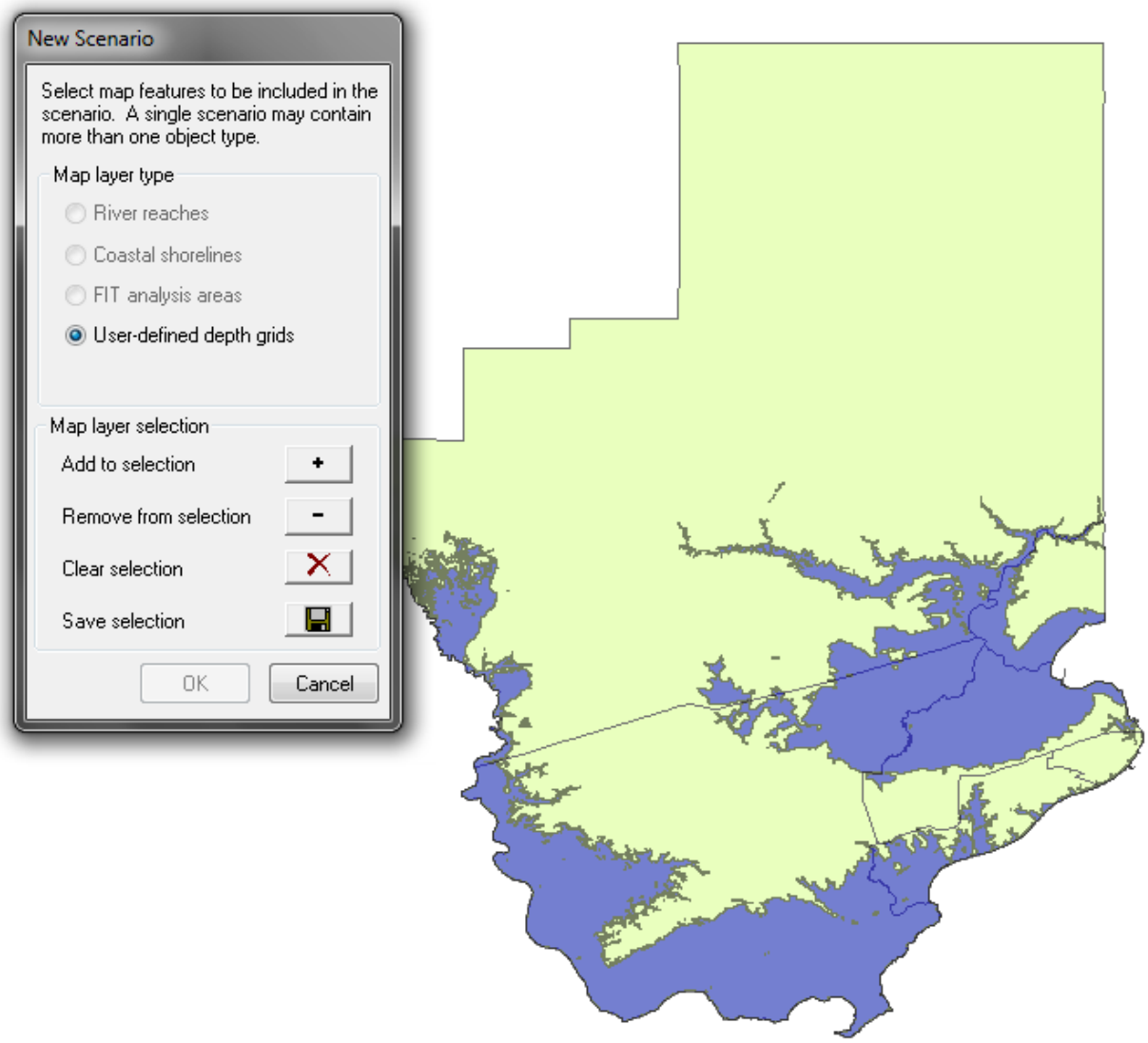


Figure 43. Use the scenario wizard to select your depth grid for analysis in Hazus.

C. After the depth grid is loaded into the new scenario, the coastal hazard analysis must be run by going to the Hazus menu, and choosing Coastal, and then choosing Delineate Floodplain. Once the Coastal Hazard Analysis menu (Figure 44) appears click Ok, then Yes. At the conclusion of this step, the level-1 analysis with improved hazard data (thus possibly level-2) may be performed.

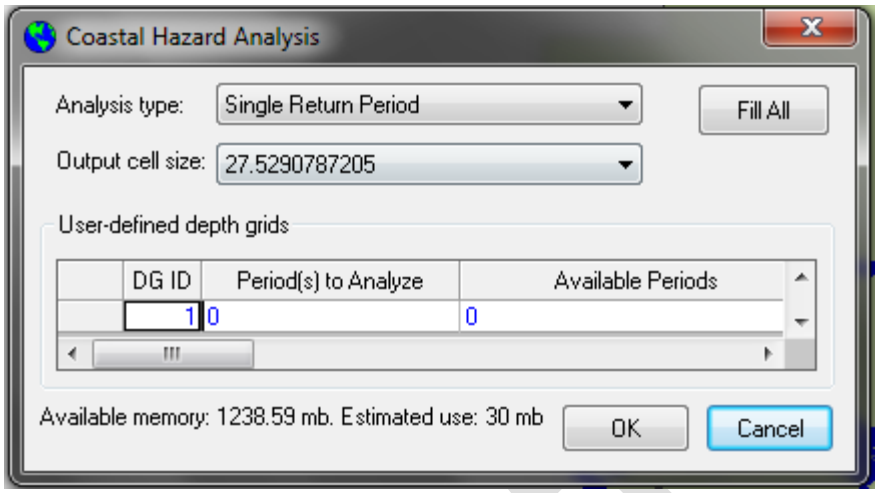


Figure 44. After supplying a depth grid, you need to delineate the coastal floodplain.

D. In the Analysis menu, choose Run, select the analysis options listed below, and then click OK to run the analysis (which will take some time to complete). Proceed to Step 6 when the analysis is complete.

Place a checkmark in the following boxes (Figure 45 below):

- General Building Stock Damage and Loss
- Essential Facilities
- Transportation Systems
- Utility Systems
- Vehicles
- Debris
- Direct Social Loss
- Indirect Economic Loss

All-sub-boxes will automatically be selected by placing checkmarks in the above boxes.

DRAFT

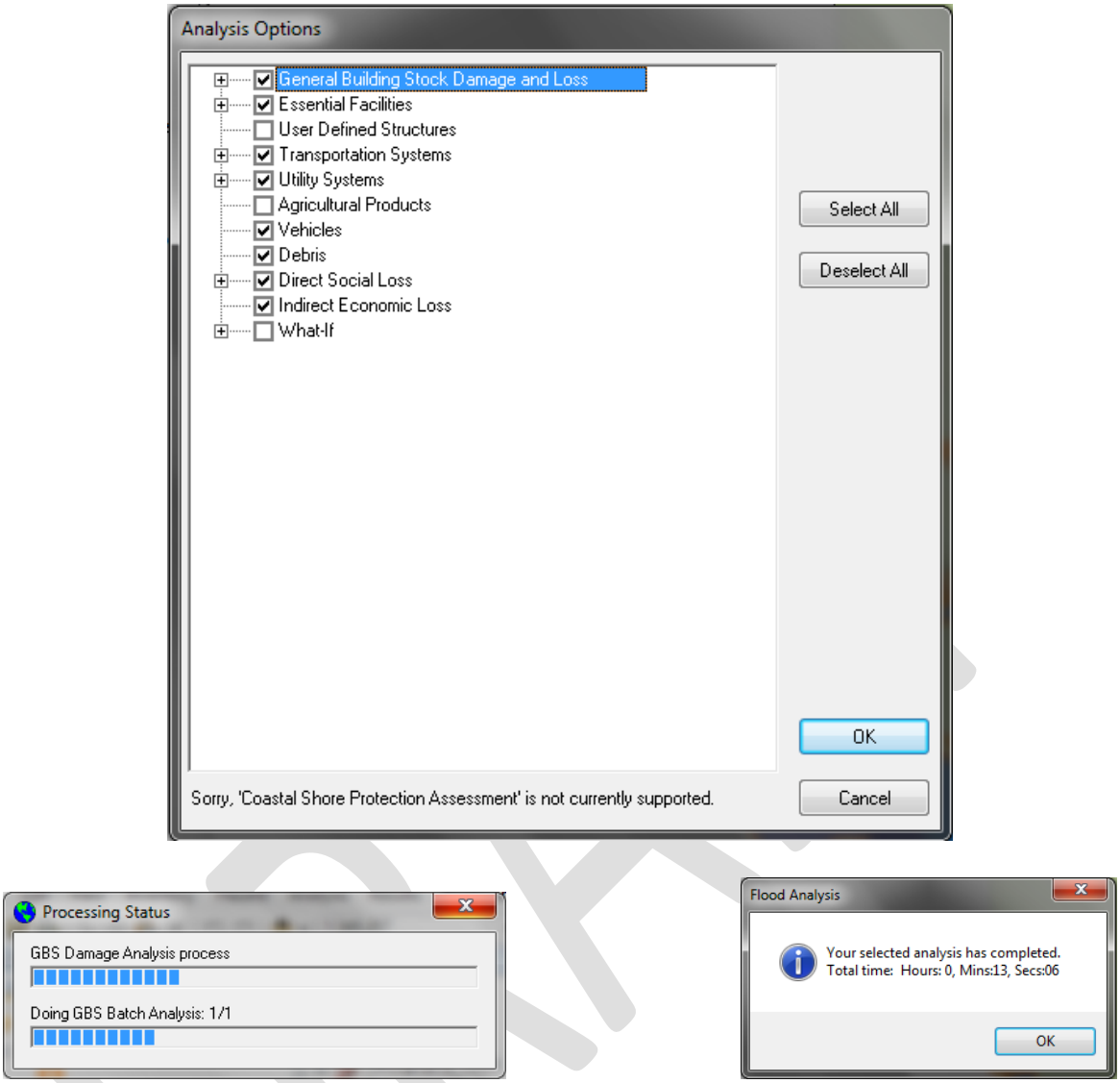


Figure 45. Hazus Analysis options, processing status, and analysis time.

Step 6: Archive Results and HPR

A. Go to the Results menu and choose View Current Scenario Results By…, and a window (Figure 46) will appear, simply click OK.

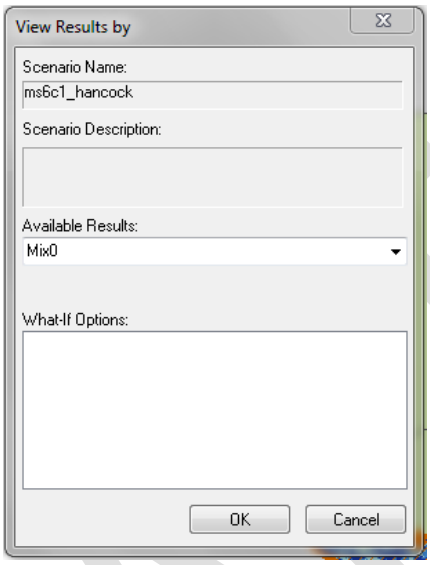


Figure 46. View Scenario by Results.

Then go to the Results menu again and click on Summary Reports. When the summary reports dialog box appears, click on the Losses tab, and then select "Direct Economic Losses for Buildings" (DELB), then navigate to the Other tab, and click on "Global Summary Report". These lists are shown in Figure 46 below. Once both reports are selected, click View, and both reports will appear. It is recommended to save the reports in a single location as a .pdf for quick viewing at a later date. Since each county will have 10 reports generated (Category 1-5 Global Summary Reports and Category 1-5 DELB) it is recommended that you a file structure similar to that of Figure 1.

DRAFT

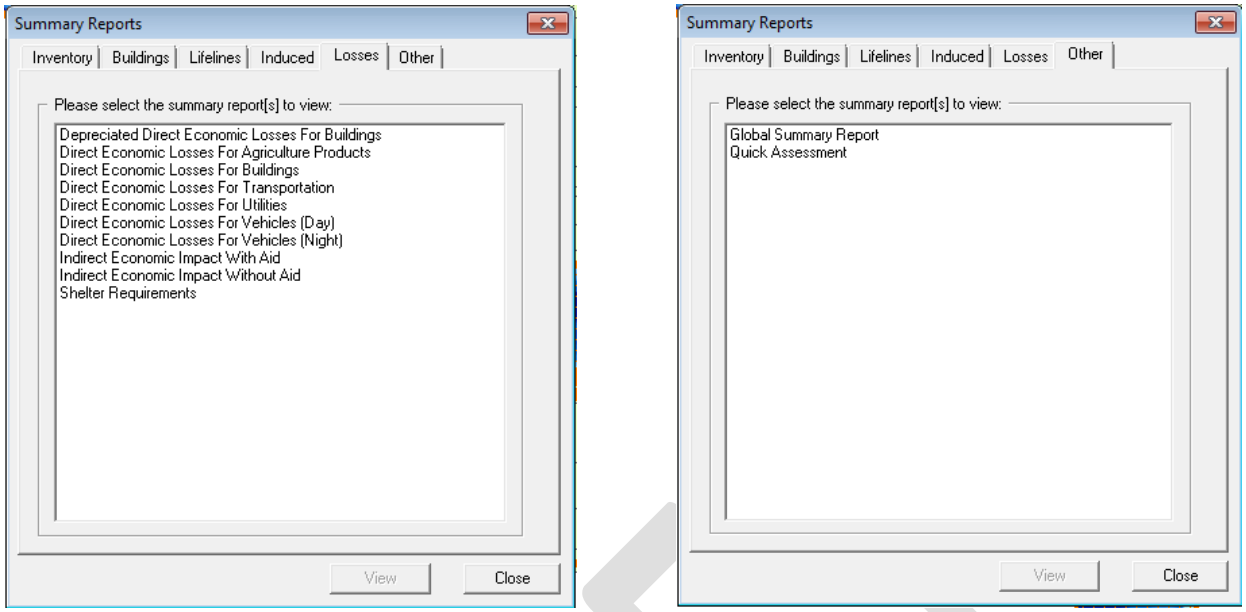


Figure 47. Hazus Summary Reports menu for Direct Economic Losses for Buildings (DELB) and Global Summary Report.

B. Once the reports are generated and saved, the following attributes will be collected (The Risk Analysis Team manually inputs the data via an Excel Spreadsheet):

- Global Summary Report
  - Population 2000
  - County Area in Square Miles
  - Hazus Building Total
  - Hazus Building Value
  - Hazus Percent Buildings Residential
  - Hazus Building Residential Exposure
  - Hazus Hospital Beds
  - Hazus Percent Residential Buildings Substantially Damaged
  - Hazus Number of Fire Stations Substantially Damaged
  - Hazus Number of Schools Substantially Damaged
  - Hazus Number of Police Stations Substantially Damaged
  - Hazus Number of Hospitals Substantially Damaged
  - Debris Total in Tons
  - Debris Total in Truck Loads
  - Displaced Households
  - Potential Shelter Population
  - Total Replacement Value %
- Direct Economic Loss to Buildings (DELB)
  - Cost Building Damage
  - Building Loss Ration %

Once you have populated your spreadsheet with the analysis results, you need to export the Hazus region.

DRAFT

C. Similar to saving the Hazus crystal reports, it is important to create a dependable and management file structure similar to that of Figure 1 for your Hazus Packed Regions (HPRs). To do this, the first thing that you will need to do is to close ArcMap. It will prompt you to save the map document, and click NO. Then open Hazus and chose the Export/Backup a region option and click OK, and the Export/Backup Region window will appear (Figure 48).

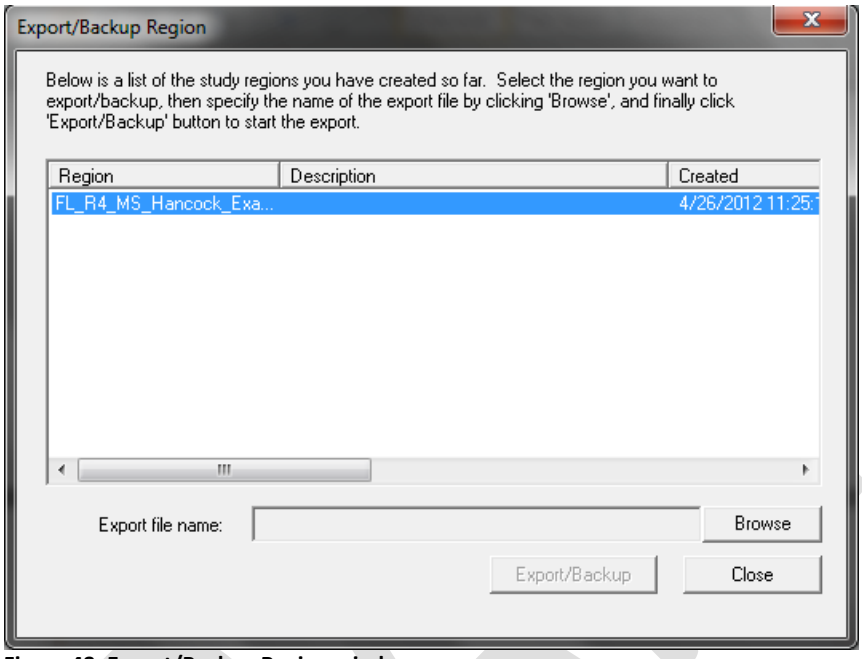


Figure 48. Export/Backup Region window.

Click ON Browse and navigate to the appropriate location to save the HPR, click Save. This will return you to the original Export/Backup Region window. Now you are ready to export the HPR, so click Export/Backup. It will take a few minutes to export, and when the process is complete, a window will pop up confirming that the region has been exported (Figure 49 below). Click Ok, and then Close. This will return you to the Hazus Startup Menu. From here you can either delete the region, since you have already back it up, or create a new region and repeat the process for the next county.

Figure 49. Region export completed window.

Conclusion and Future Work

Conclusion

The work behind the Coastal Flood Loss Methodology presented here was developed following the 2006 hurricane season by Planning and Mitigation specialists to create a storm surge loss atlas. As the process moved forward, FEMA in turn adopted this standard operating procedure (SOP) in 2008 for mitigation strategy and operational use during the landfall of tropical systems. This proven method proved useful during the responses to Hurricanes Dolly (2008), Gustav (2008), Ike (2008), Earl (2010), and Irene (2011). Although the Coastal Flood Loss Atlas was initially created to cover coastal areas of FEMA Region IV (Mississippi, Alabama, Florida, Georgia, South Carolina, and North Carolina), the most recent version (CFLA V3.0) has been expanded to include all coastal areas in FEMA Regions, I, II, III, IV, and VI, with the exception of the US Virgin Islands and Puerto Rico.

In addition to the extension to the spatial coverage of the CFLA, the Coastal Flood Methodology has been adapted to fit other flooding events that are unrelated to storm surge associated with landfalling tropical cyclones. In 2009, the Risk Analysis Team produced a Tsunami inundation depth gird for the Pacific island of Guam in coordination with FEMA Region IX. In turn using the methodology above, Hazus loss estimates were generated for the island. This methodology has also been implemented during the response for the Alaska Superstorm in 2011 where global forecast models outputs were used to create a surge gird similar to the SLOSH output, which was used to create an extratropical cyclone surge depth grid. This depth grid was then used to run a Hazus analysis for the event in Nome, AK. A similar method was used during the 2011 Flooding events in Kentucky, Tennessee, and North Dakota. In these case studies, high water mark data was collected and this data was used to create a flood surface elevation. From that point, a depth grid was created by subtracting the DEM, and a Hazus analysis was ran by using the user defined depth grid. For more information these and other applications using the Coastal Flood Loss Methodology refer to Appendix D: Applications and Available Products from the CFLA.

Future Work

The Risk Analysis Team has outlined the next two versions of the CFLA (CFLA V4.0 – Summer 2012; CFLA V5.0 – Summer 2013). CFLA V4.0 will include the following additions:

- Updated SLOSH basins
- Loss analysis completed in Hazus 2.1
- Inland Counties Experiencing Storm Surge Flooding
- Depth Grids and Loss Analysis for the Lake Okeechobee, Hawaii, Puerto Rico, and USVI Basins
- Population Exposure per Hurricane Category
- Housing Exposure per Hurricane Category
- Demographic Analysis Exposure per Hurricane Category
- Social Vulnerability (SoVI) variable rank
- Limited parcel and other point exposure analysis (NFIP) where available
- Limited DFIRM analysis where available
- Climatology and Strike Frequency Data

DRAFT

- Historical Hurricane Loss Data
- County Mean Surge Value per Hurricane Category
- Coastal versus Riverine Damage Function Desingation

CFLA V5.0 will incorporate more local data (where available), including a parcel level analysis, and NFIP policy and DFIRM review. This version will also expand from tropical cyclone induced surge flooding, and include extratropical cyclone induced flooding and tsunami flooding (Hazus Tsunami Module expected in 2013). The planned additions include everything from the version 4.0 update and the following:

- Updated SLOSH basins
- Loss Analysis with the most recent version of Hazus
- Updated data to reflect the current demographics
- Parcel exposure attribute (where available)
- Transition to Block-Level Analysis
- Data Extraction Tool
- Ongoing Public Assistance, Individual Assistance, and Hazard Mitigation Assistance Project Exposure

The CFLA V6.0 will expand on the previous versions of the CFLA, and its updates are still under development. This version is expected to be available in 2015.

DRAFT

Appendix A: How to Install the ET GeoWizards Software

The VERTCON – Version 2.1 (last updated September 2003) is available from the national Geodetic Survey at: http://www.ngs.noaa.gov/PC_PROD/VERTCON/.

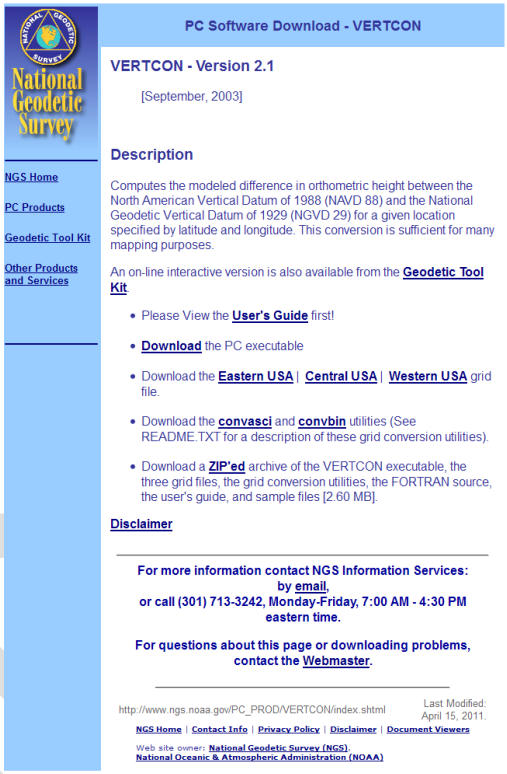


Figure 50. VERTCON download page on the National Geodetic Survey website.

Click "ZIP'ed" to download the full archive of the VERTCON executable file. This will ensure that you have the most up to date version and will allow you to save your .dbf, .prn, and .out files in the same location as the VERCON.exe file. It is recommended that when unzip VERTCON.zip that you save it to the root of your C drive. At this point you may need to obtain administrator privileges on your machine to place the file directly on to the root of the C drive, if you are unable to obtain administrator privileges, please have your IT place this file there. It is highly recommended that this file be placed in this location.

Appendix B: Hurricane Dolly CONOPS

The following maps were generated in response to Hurricane Dolly following the event strategy set out in the CONOPS Timeline referred to at page xii herein. Real-time SLOSH runs posted to the National Hurricane Center's FTP website were downloaded and converted for use within HAZUS per the SOP methodology. Careful QA/QC review of the SLOSH shapefiles revealed errors which prevented Hazus analyses for Advisory #12, whereas products were successfully produced pursuant to the SOP for NHC Advisories #10 and #13 (landfall).

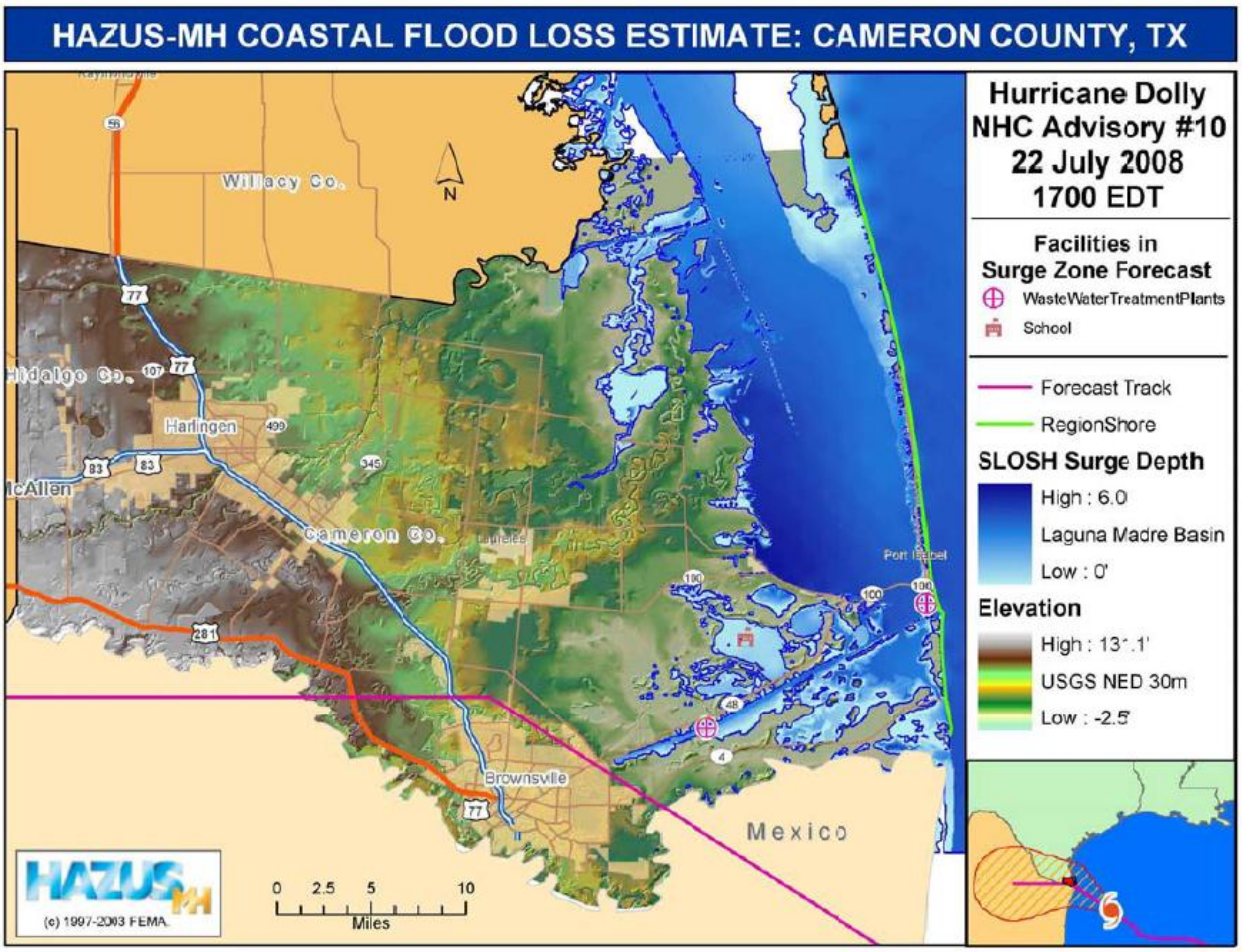


Figure 51. Potentially flooded facilities (Level-1 Hazus data) for Hurricane Dolly at NHC Advisory #10.

Figure 52. Potentially flooded facilities (Level-1 Hazus data) for Hurricane Dolly at NHC Advisory #13.

Appendix C: Python Script to Clip Multiple Counties

As discussed in Step 4: Hazus Depth Grid Tool, you are able to create one depth grid and boundary file that incorporates all of the counties within the entire SLOSH basin. The only downfall to this is that they are not clipped to the individual county. To clip the depth grids and boundary files to the county level is a simple geoprocess, however the time required for this process each county 10 times is extensive. Therefore the FEMA Region IV Risk Analysis Team developed a python script for this process. The following script is an example using the GL2 (Galveston Bay) basin.

```
import sys, os, string, arcgisscripting
gp = arcgisscripting.create()
gp.workspace = "E:\DG_Creation"
gp.overwriteoutput = 1
gp.CheckOutExtension("Spatial")
coordsys = "Coordinate Systems/Geographic Coordinate Systems/North America/North American Datum 1983.prj"

#Importing and assigning names to the depth grids by basin and category...
print 'Importing and assigning names to the depth grids by basin and category...'
GL2c1="E:\DGCreation\GL2_20120213\gl2c1dg"
GL2c2="E:\DGCreation\GL2_20120213\gl2c2dg"
GL2c3="E:\DGCreation\GL2_20120213\gl2c3dg"
GL2c4="E:\DGCreation\GL2_20120213\gl2c4dg"
GL2c5="E:\DGCreation\GL2_20120213\gl2c5dg"


#Importing and assigning names to the inundation footprints by basin and category...
print 'Importing and assigning names to the inundation footprints by basin and category...'
GL2c1b="E:\DGCreation\GL2_20120213\GL2_c1boundary.shp"
GL2c2b="E:\DGCreation\GL2_20120213\GL2_c2boundary.shp"
GL2c3b="E:\DGCreation\GL2_20120213\GL2_c3boundary.shp"
GL2c4b="E:\DGCreation\GL2_20120213\GL2_c4boundary.shp"
GL2c5b="E:\DGCreation\GL2_20120213\GL2_c5boundary.shp"


#Importing and naming HAZUS county shapefiles to clip with...
print 'Importing and naming HAZUS county shapefiles to clip with...'
TX_Liberty="H:\HazardData\FL\SHP\CountiesV4\TX_Liberty.shp"
TX_Galveston="H:\HazardData\FL\SHP\CountiesV4\TX_Galveston.shp"
TX_Chambers="H:\HazardData\FL\SHP\CountiesV4\TX_Chambers.shp"
TX_Harris="H:\HazardData\FL\SHP\CountiesV4\TX_Harris.shp"


#Clip depth grids with county shapefiles
#Start with Category 1 depth Grids
print 'Clipping Category 1 depth grids with HAZUS counties...'
gp.ExtractByMask_sa(GL2c1,TX_Liberty,"E:\DGCreation\GL2_20120213\GL2\TX_Liberty\GL2c1dg")
gp.ExtractByMask_sa(GL2c1,TX_Galveston,"E:\DGCreation\GL2_20120213\GL2\TX_Galveston\GL2c1dg")
```

DRAFT

```
gp.ExtractByMask_sa(GL2c1,TX_Chambers,"E:\DGCreation\GL2_20120213\GL2\TX_Chambers\GL2c1dg")
gp.ExtractByMask_sa(GL2c1,TX_Harris,"E:\DGCreation\GL2_20120213\GL2\TX_Harris\GL2c1dg")

print 'Clipping Category 2 depth grids with HAZUS counties...'
gp.ExtractByMask_sa(GL2c2,TX_Liberty,"E:\DGCreation\GL2_20120213\GL2\TX_Liberty\GL2c2dg")
gp.ExtractByMask_sa(GL2c2,TX_Galveston,"E:\DGCreation\GL2_20120213\GL2\TX_Galveston\GL2c2dg")
gp.ExtractByMask_sa(GL2c2,TX_Chambers,"E:\DGCreation\GL2_20120213\GL2\TX_Chambers\GL2c2dg")
gp.ExtractByMask_sa(GL2c2,TX_Harris,"E:\DGCreation\GL2_20120213\GL2\TX_Harris\GL2c2dg")

print 'Clipping Category 3 depth grids with HAZUS counties...'
gp.ExtractByMask_sa(GL2c3,TX_Liberty,"E:\DGCreation\GL2_20120213\GL2\TX_Liberty\GL2c3dg")
gp.ExtractByMask_sa(GL2c3,TX_Galveston,"E:\DGCreation\GL2_20120213\GL2\TX_Galveston\GL2c3dg")
gp.ExtractByMask_sa(GL2c3,TX_Chambers,"E:\DGCreation\GL2_20120213\GL2\TX_Chambers\GL2c3dg")
gp.ExtractByMask_sa(GL2c3,TX_Harris,"E:\DGCreation\GL2_20120213\GL2\TX_Harris\GL2c3dg")

print 'Clipping Category 4 depth grids with HAZUS counties...'
gp.ExtractByMask_sa(GL2c4,TX_Liberty,"E:\DGCreation\GL2_20120213\GL2\TX_Liberty\GL2c4dg")
gp.ExtractByMask_sa(GL2c4,TX_Galveston,"E:\DGCreation\GL2_20120213\GL2\TX_Galveston\GL2c4dg")
gp.ExtractByMask_sa(GL2c4,TX_Chambers,"E:\DGCreation\GL2_20120213\GL2\TX_Chambers\GL2c4dg")
gp.ExtractByMask_sa(GL2c4,TX_Harris,"E:\DGCreation\GL2_20120213\GL2\TX_Harris\GL2c4dg")

print 'Clipping Category 5 depth grids with HAZUS counties...'
gp.ExtractByMask_sa(GL2c5,TX_Liberty,"E:\DGCreation\GL2_20120213\GL2\TX_Liberty\GL2c5dg")
gp.ExtractByMask_sa(GL2c5,TX_Galveston,"E:\DGCreation\GL2_20120213\GL2\TX_Galveston\GL2c5dg")
gp.ExtractByMask_sa(GL2c5,TX_Chambers,"E:\DGCreation\GL2_20120213\GL2\TX_Chambers\GL2c5dg")
gp.ExtractByMask_sa(GL2c5,TX_Harris,"E:\DGCreation\GL2_20120213\GL2\TX_Harris\GL2c5dg")


#Clip inundation footprints with county shapefiles
#Start with Category 1 inundation footprints
print 'Clipping Category 1 inundation footprints with HAZUS counties...'
gp.Clip_analysis(GL2c1b,TX_Liberty,"E:\DGCreation\GL2_20120213\GL2\TX_Liberty\Liberty_c1boundary.shp")
gp.Clip_analysis(GL2c1b,TX_Galveston,"E:\DGCreation\GL2_20120213\GL2\TX_Galveston\Galveston_c1boundary.
shp")
gp.Clip_analysis(GL2c1b,TX_Chambers,"E:\DGCreation\GL2_20120213\GL2\TX_Chambers\Chambers_c1boundary.
shp")
gp.Clip_analysis(GL2c1b,TX_Harris,"E:\DGCreation\GL2_20120213\GL2\TX_Harris\Harris_c1boundary.shp")

print 'Clipping Category 2 inundation footprints with HAZUS counties...'
gp.Clip_analysis(GL2c2b,TX_Liberty,"E:\DGCreation\GL2_20120213\GL2\TX_Liberty\Liberty_c2boundary.shp")
gp.Clip_analysis(GL2c2b,TX_Galveston,"E:\DGCreation\GL2_20120213\GL2\TX_Galveston\Galveston_c2boundary.
shp")
gp.Clip_analysis(GL2c2b,TX_Chambers,"E:\DGCreation\GL2_20120213\GL2\TX_Chambers\Chambers_c2boundary.
shp")
gp.Clip_analysis(GL2c2b,TX_Harris,"E:\DGCreation\GL2_20120213\GL2\TX_Harris\Harris_c2boundary.shp")

print 'Clipping Category 3 inundation footprints with HAZUS counties...'
gp.Clip_analysis(GL2c3b,TX_Liberty,"E:\DGCreation\GL2_20120213\GL2\TX_Liberty\Liberty_c3boundary.shp")
gp.Clip_analysis(GL2c3b,TX_Galveston,"E:\DGCreation\GL2_20120213\GL2\TX_Galveston\Galveston_c3boundary.
shp")
gp.Clip_analysis(GL2c3b,TX_Chambers,"E:\DGCreation\GL2_20120213\GL2\TX_Chambers\Chambers_c3boundary.
shp")
gp.Clip_analysis(GL2c3b,TX_Harris,"E:\DGCreation\GL2_20120213\GL2\TX_Harris\Harris_c3boundary.shp")
```

```
print 'Clipping Category 4 inundation footprints with HAZUS counties...'
gp.Clip_analysis(GL2c4b,TX_Liberty,"E:\DGCreation\GL2_20120213\GL2\TX_Liberty\Liberty_c4boundary.shp")
gp.Clip_analysis(GL2c4b,TX_Galveston,"E:\DGCreation\GL2_20120213\GL2\TX_Galveston\Galveston_c4boundary.
shp")
gp.Clip_analysis(GL2c4b,TX_Chambers,"E:\DGCreation\GL2_20120213\GL2\TX_Chambers\Chambers_c4boundary.
shp")
gp.Clip_analysis(GL2c4b,TX_Harris,"E:\DGCreation\GL2_20120213\GL2\TX_Harris\Harris_c4boundary.shp")

print 'Clipping Category 5 inundation footprints with HAZUS counties...'
gp.Clip_analysis(GL2c5b,TX_Liberty,"E:\DGCreation\GL2_20120213\GL2\TX_Liberty\Liberty_c5boundary.shp")
gp.Clip_analysis(GL2c5b,TX_Galveston,"E:\DGCreation\GL2_20120213\GL2\TX_Galveston\Galveston_c5boundary.
shp")
gp.Clip_analysis(GL2c5b,TX_Chambers,"E:\DGCreation\GL2_20120213\GL2\TX_Chambers\Chambers_c5boundary.
shp")
gp.Clip_analysis(GL2c5b,TX_Harris,"E:\DGCreation\GL2_20120213\GL2\TX_Harris\Harris_c5boundary.shp")

print 'Done'
```

DRAFT

Appendix D: Applications and Available Products of the CFLA

The development of the Coastal Flood Loss Atlas was intended for use in mitigation and disaster operations planning. Over time, the CFLA has been evolved into a tool expanding beyond its original use. Recently, the CFLA has been used to support local, state, and national level hurricane exercises focused on hurricane and the associated surge (see Appendix H: Exercise Use). In addition to exercise use, the CFLA and Coastal Flood Loss Methodology has been used during disaster operations in the response planning and future planning sections by FEMA Regions I, II, III, VI, VI, VIII, IX, and X Regional Response Coordination Centers (RRCCs) and the National Response Coordination Center (NRCC). Included in this appendix is an in-depth analysis of the events that the CFLA or Coastal Flood Loss Methodology has supported since its induction.

Hurricane Storm Surge

The Coastal Flood Loss Methodology and the Coastal Flood Loss Atlas was established so that mitigation and disaster operational planners so that they could have a quick reference dictionary for pre event storm surge Hazus loss scenarios. This model has been proved effective and extremely useful by way of the following events:

- Hurricane Dolly 2008
- Hurricane Gustav 2008
- Hurricane Ike 2008
- Hurricane Earl 2010
- Hurricane Irene 2011

The first disaster operation use of the Coastal Flood Loss Methodology was during Hurricane Dolly in 2008 (Appendix B: Hurricane Dolly CONOPS). This storm established the baseline for how usefully the methodology was during disaster response operations. After proving its self useful during Hurricane Dolly, Hurricane Gustav a few weeks later reinforced its proved usefulness. With the proven significance of the Coastal Flood Loss Methodology and its ability to transform storm surge grids, into a useable depth grids for Hazus analysis, and the above active hurricane season of 2008, the Coastal Flood Methodology gained notoriety through all levels of government. During the response to Hurricane Ike in 2008, President George W. Bush got a first-hand look at the potential flooding and Hazus output (Figure 53). Along with the methodology and depth grids produced, another outcome has been the ability to display the amount of water above ground, versus the height of the water or water surface elevation (SLOSH output).

DRAFT

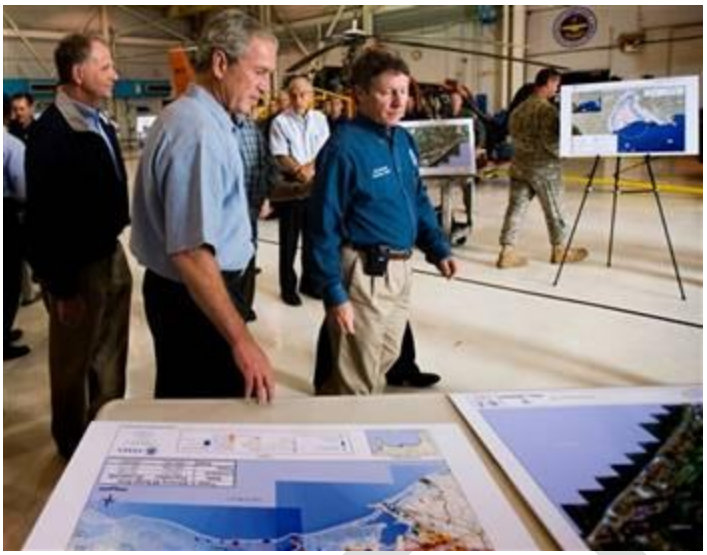


Figure 53. President George W. Bush reviewing products derived from the Coastal Flood Loss Methodology and CFLA at the Biloxi TRO during the Hurricane Ike activation 2008.

With the lessons learned from the 2008 Atlantic Hurricane Season, the development of the Coastal Flood Loss Atlas began, focusing on Region 4 at first, then spreading to 6, and 1, 2, and 3, so that the most recent version of the CFLA includes FEMA Region 1-4; 6 excluding the US Virgin Islands and Puerto Rico. The need for a pre-disaster mitigation tool such as the CFLA became apparent in 2011 when Hurricane Irene was taking aim along the Atlantic Coast, from South Carolina to Maine. Below are some products that were used to support the Hurricane Irene response in FEMA Region IV.

NOTE: Although on Region IV maps are displayed in this SOP, the CFLA, depth grids, and boundary files were used by FEMA Regions I, II, III, and IV, RRCC and by the NRCC.

DRAFT

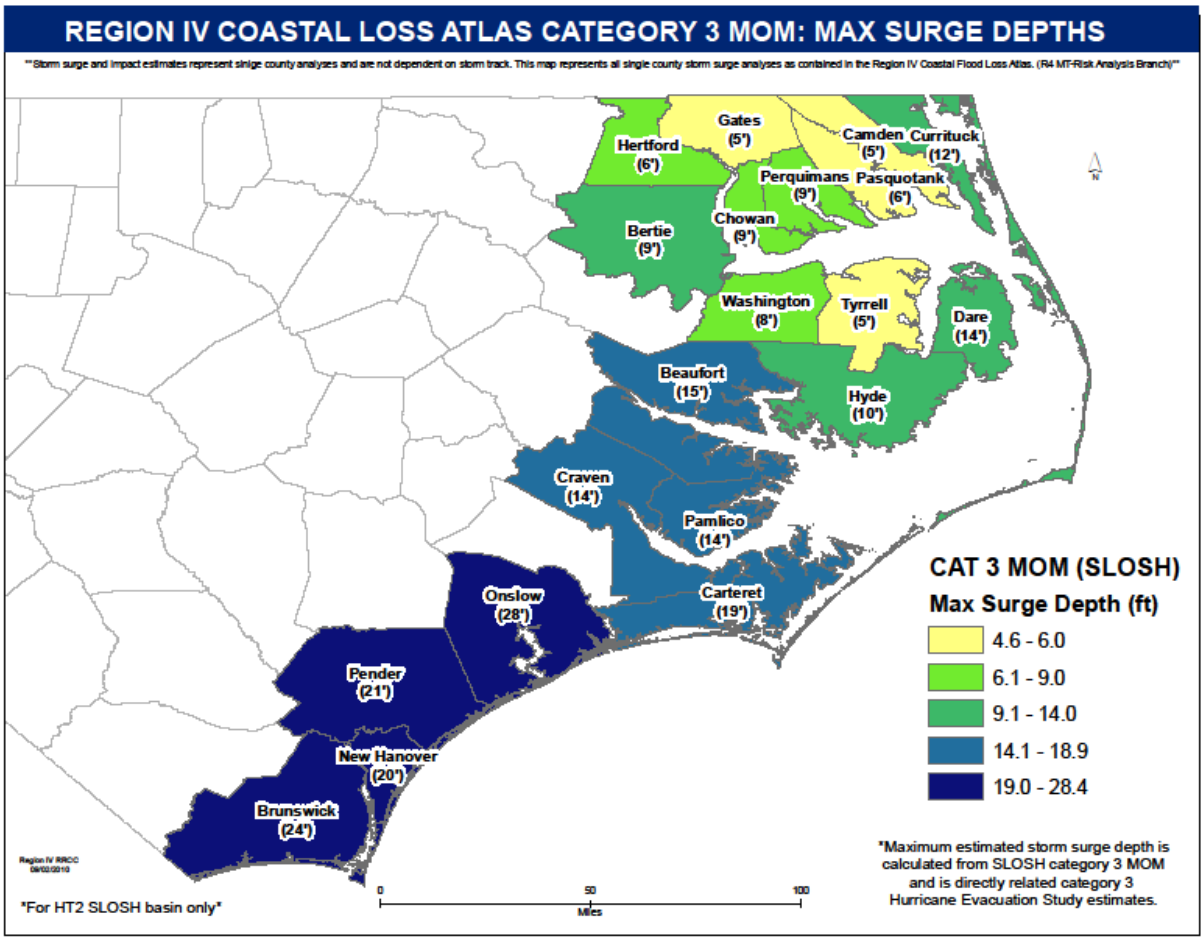


Figure 54. Region IV Coastal Surge Maximum Estimates for North Carolina - Hurricane Irene.

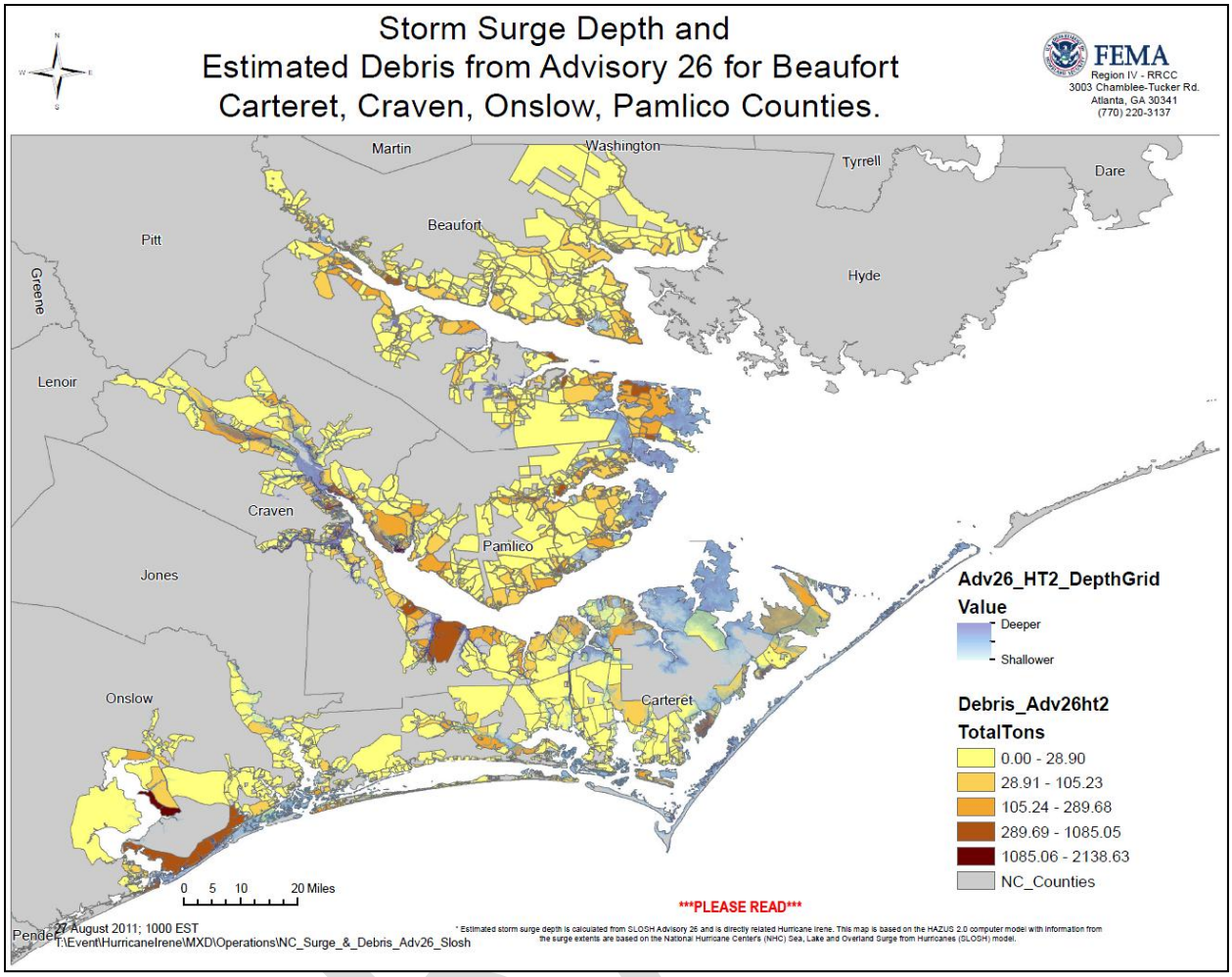


Figure 55. Storm Surge Depths and Estimated Debris from Hurricane Irene advisory 26.

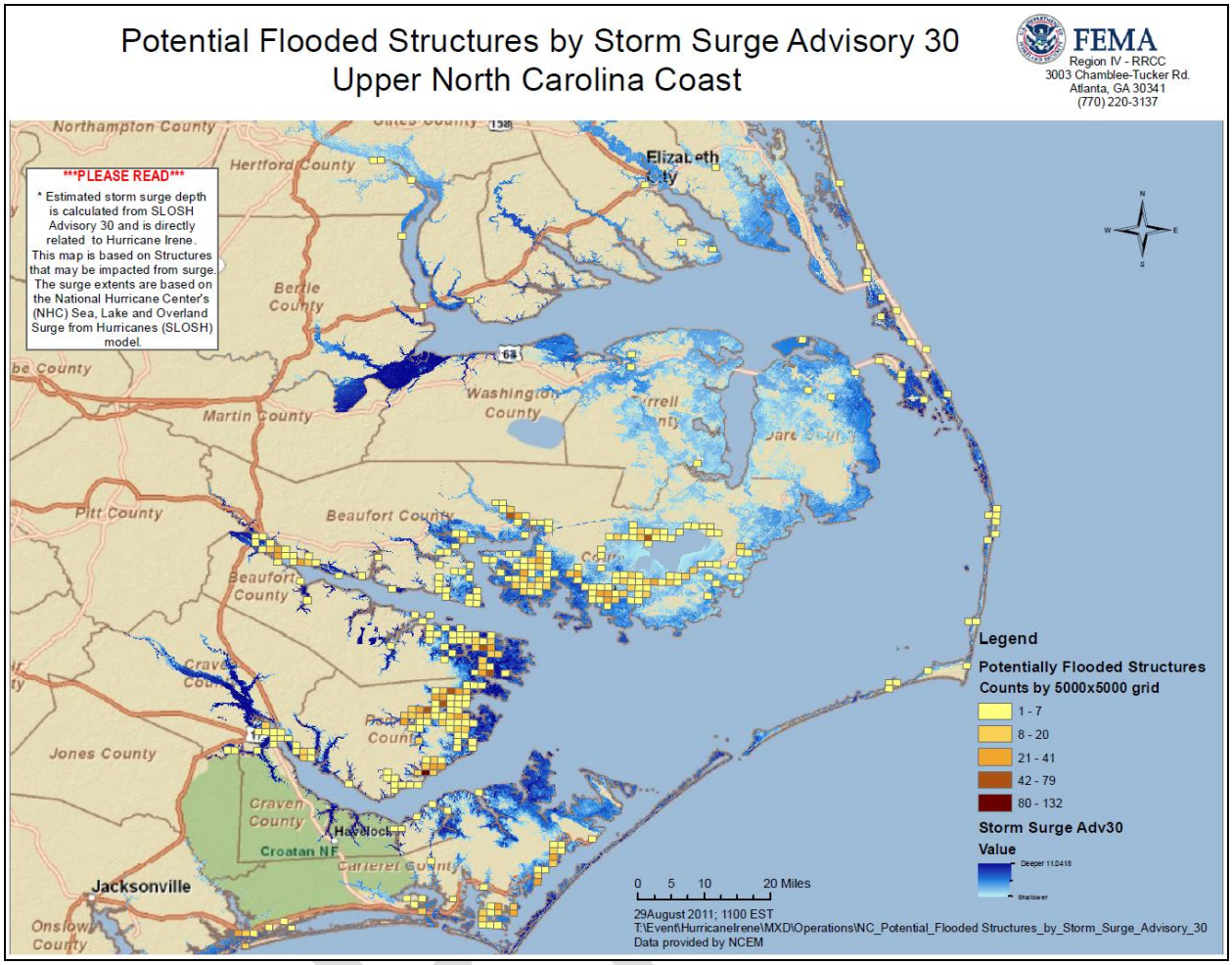


Figure 56. Potentially flooding structures based on Hurricane Irene advisory 30 and first floor elevations.

In addition to the CFLA and Coastal Flood Methodology, FEMA Region IV has led the way in establishing the collection of perishable data during all types of flooding events. During Hurricane Irene the U. S Geological Survey (USGS) deployed a temporary monitoring network of water-level sensors at 212 locations from South Carolina to Maine to record the timing, areal extent, and magnitude of the inland hurricane storm tide and coastal flooding. Water-level sensors locations were chosen based upon the location of existing tide-gage network to ensure that the monitored area would be in the area forecasted to have substantial storm surge. With the deployment of these sensors, members of the USGS, FEMA, and the U. S. Army Core of Engineers (USACE) were able to monitor the level of storm surge inundation simultaneously while the hurricane was making landfall. The web portal and graphic output are seen in the figures below. For more details about the high water mark data collection, mission assignments, and MOU, please contact the FEMA Region IV Risk Analysis Team.

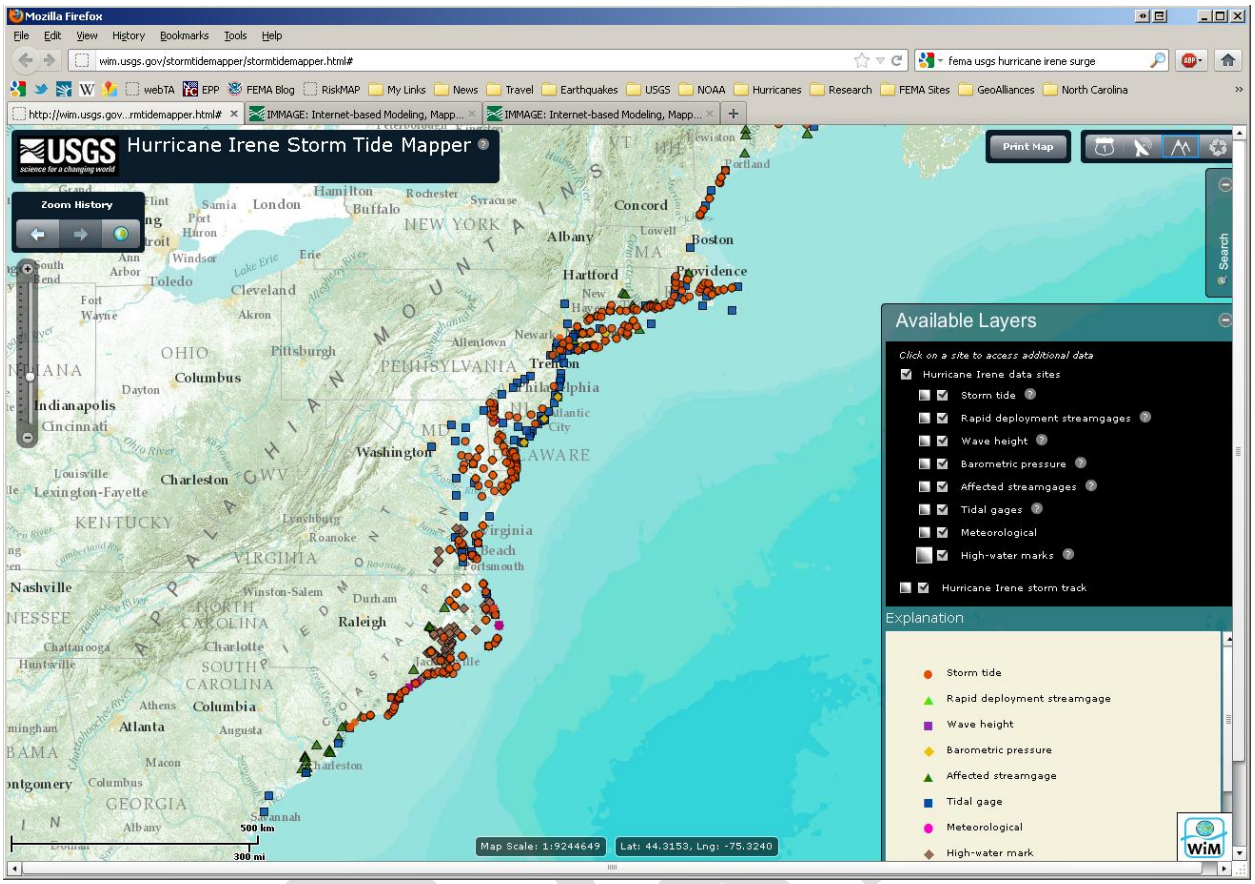


Figure 57. The USGS Hurricane Irene Storm Tide Mapper, allows for real-time visualization of the storm tide related to Hurricane Irene in 2011. (http://wim.usgs.gov/stormtidemapper/stormtidemapper.html#)

DRAFT

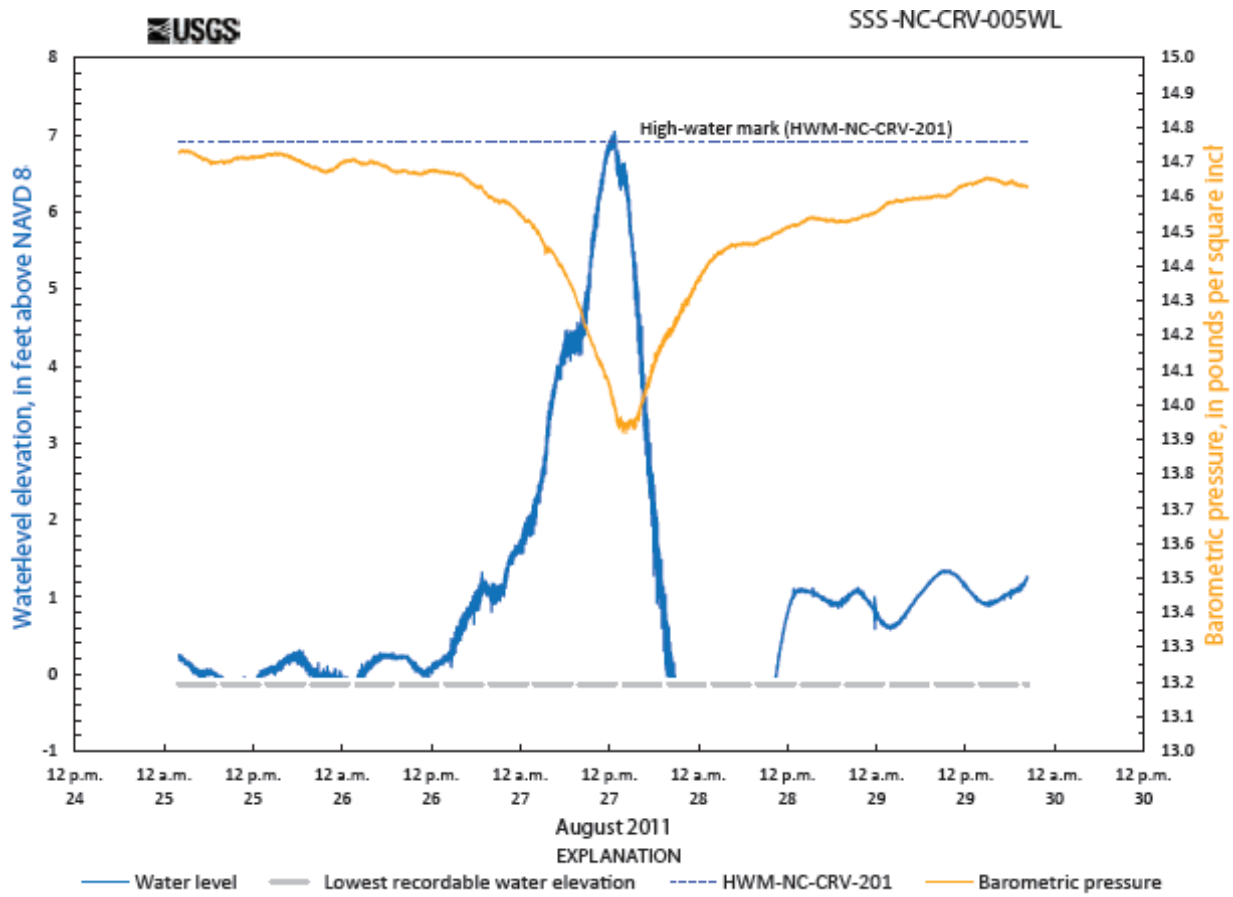


Figure 58. Example of storm-tide elevation hydrograph and barometric pressure record at the Bridgeport Hotel and Marina in Craven County, NC, during Hurricane Irene in 2011. This includes the high water mark. (http://pubs.usgs.gov/of/2012/1022/)

In recent years, the CFLA has also been adopted into the Florida's risk and vulnerability assessment portion of their state mitigation plan. Additionally, the visualization of overland flood inundation extents and the assessment of vulnerable populations and infrastructure can be found using the CFLA (Figure 59 below).

Figure 59. Category 5 MOM surge flooding visualization for Miami, FL as displayed in Google Earth.

Riverine Inundation and High Water Marks

There have been three events dealing with riverine flooding in Ohio River Flooding in Kentucky (DR-1976-KY), Mississippi River Flooding in Tennessee (DR-1979-TN), and Souris River Flooding in Minot, North Dakota (DR-1981-ND). Under a similar Mission Assignment and MOU to the USGS, FEMA has begun the collection of perishable data and in this case, high water marks (HWM).

NOTE: The preliminary high water mark data produced in figure 60 is the first time in the history of the Federal Emergency Management Agency, that HWM data was collected and developed into a depth grid within 24 hours of the Ohio River cresting. This evolution in FEMA doctrine has led to an Agency-wide change in disaster response. Without the positive feedback from the Kentucky HWMs, the HWM would have never been collected in Tennessee, Minot, and the storm tide sensors would not have been deployed prior to the landfall of Hurricane Irene.

In these events, HWM data was used in place of SLOSH MOM points to interpolate a water surface, and then the surface was subtracted from the USGS NED 30-meter DEMs to get a depth grid. This process in now widely accepted throughout the Agency. Figure 55 displays the how the Kentucky HWMs were used to develop a depth grid.

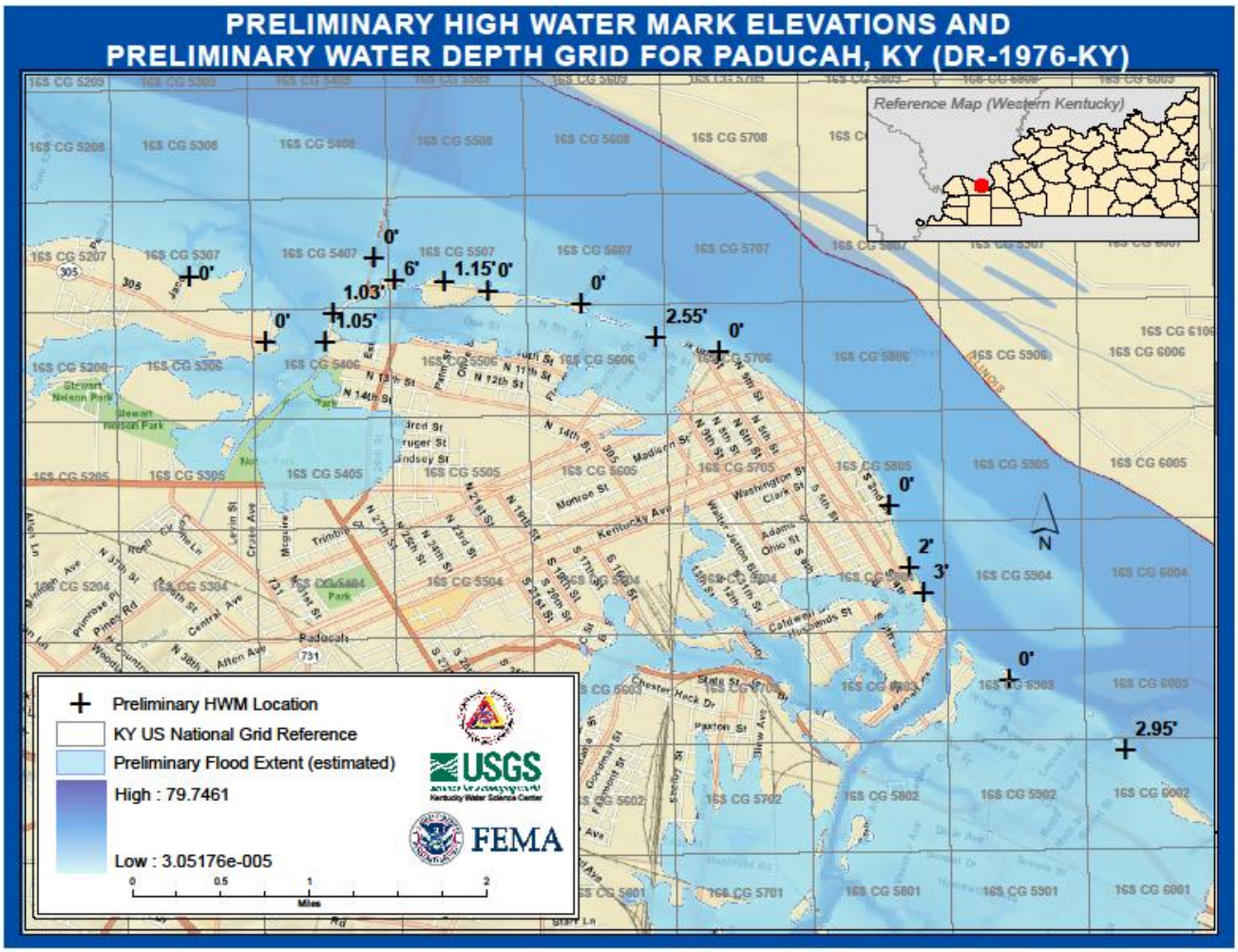


Figure 60. Preliminary HWM elevation and preliminary water depth grid for Paducah, KY.

Extratropical Cyclone Surge Analysis

In addition tropical cyclone induced storm surge flooding; the coastal flood methodology has been used to create depth grids for extratropical cyclone related surge. This was brought to action during DR-4050-AK, when an anomalously strong mid-latitude cyclone slammed into coastal Alaska. Unlike SLOSH and tropical storm surge forecast, extratropical storm surge forecasting is done via global forecast models. In this case NOAA's/NWS's Meteorological Development Laboratory (MDL) Evaluation Branch has created an extratropical storm surge model that is driven by the winds and pressures based off of the National Weather Service's Global Forecast system (GFS) atmospheric model. The GFS is also one of the major medium to long range forecast models for large scale weather events across the United States. Similar to the SLOSH, MDL has developed 6 basins that cover the entire lower 48 and Alaskan coasts. Unlike the SLOSH basins which may cover only 6-10 counties, these basins cover the entire coast (from Florida to Main). This is necessary due to the spatial extent of mid-latitude systems (in comparison to tropical cyclones), large scale basins are necessary so all boundary level conditions can be incorporated (i.e. the wind and pressure). The figure below displays the extra tropical forecast basins.

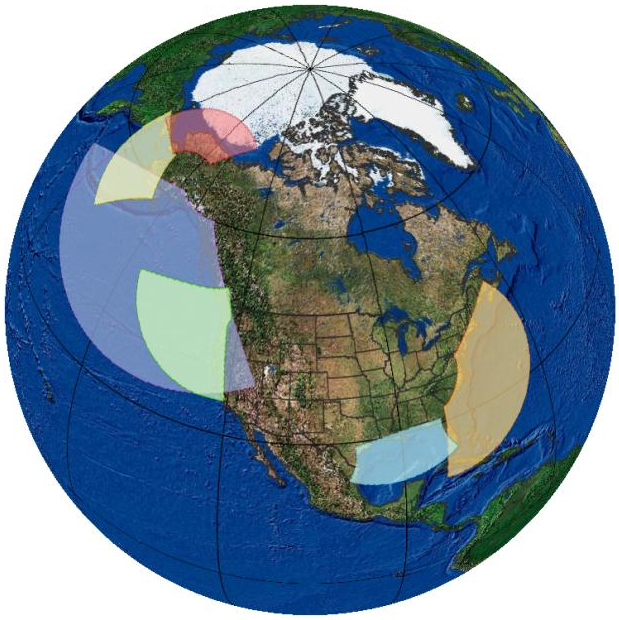


Figure 61. Extratropical cyclone forecast basins.
(http://www.nws.noaa.gov/mdl/marine/etsurge.php)

Using the same principles behind the Coastal Flood Loss Methodology, the MDL's Alaska extratropical storm surge forecasting grid (seen in figure 62 below) we were able to convert the grid into points, interpolate a water surface, and then subtract a DEM, giving us a depth grid. This depth grid was used for a Hazus analysis, and loss estimates were produced. Figure 63 displays the extra tropical storm surge depths and Hazus estimated debris in tons by census block in Nome, Alaska.

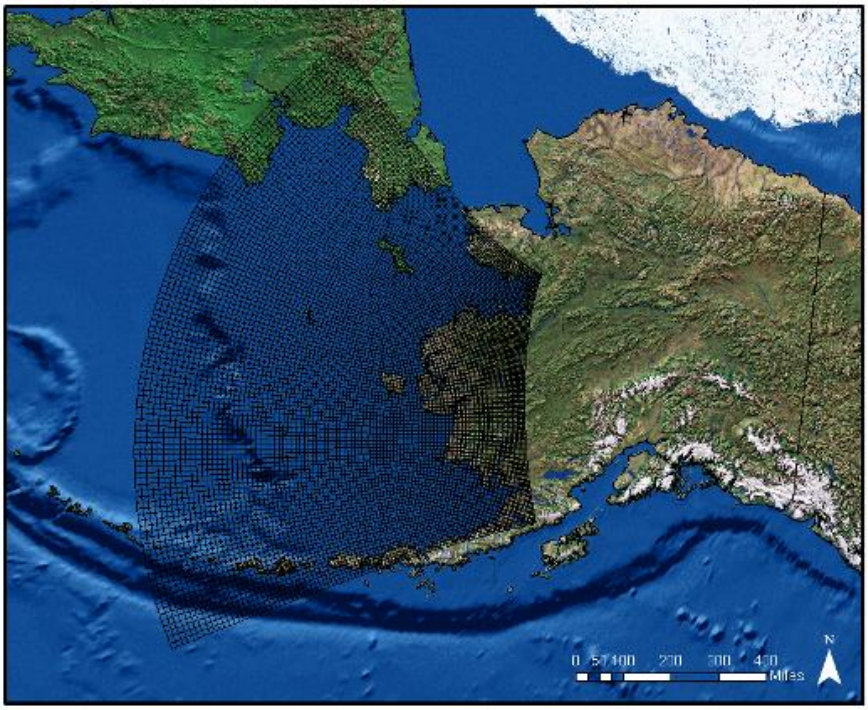


Figure 62. MDL's Alaska Extratropical Storm Surge Gird.
(http://www.nws.noaa.gov/mdl/marine/norton.php)

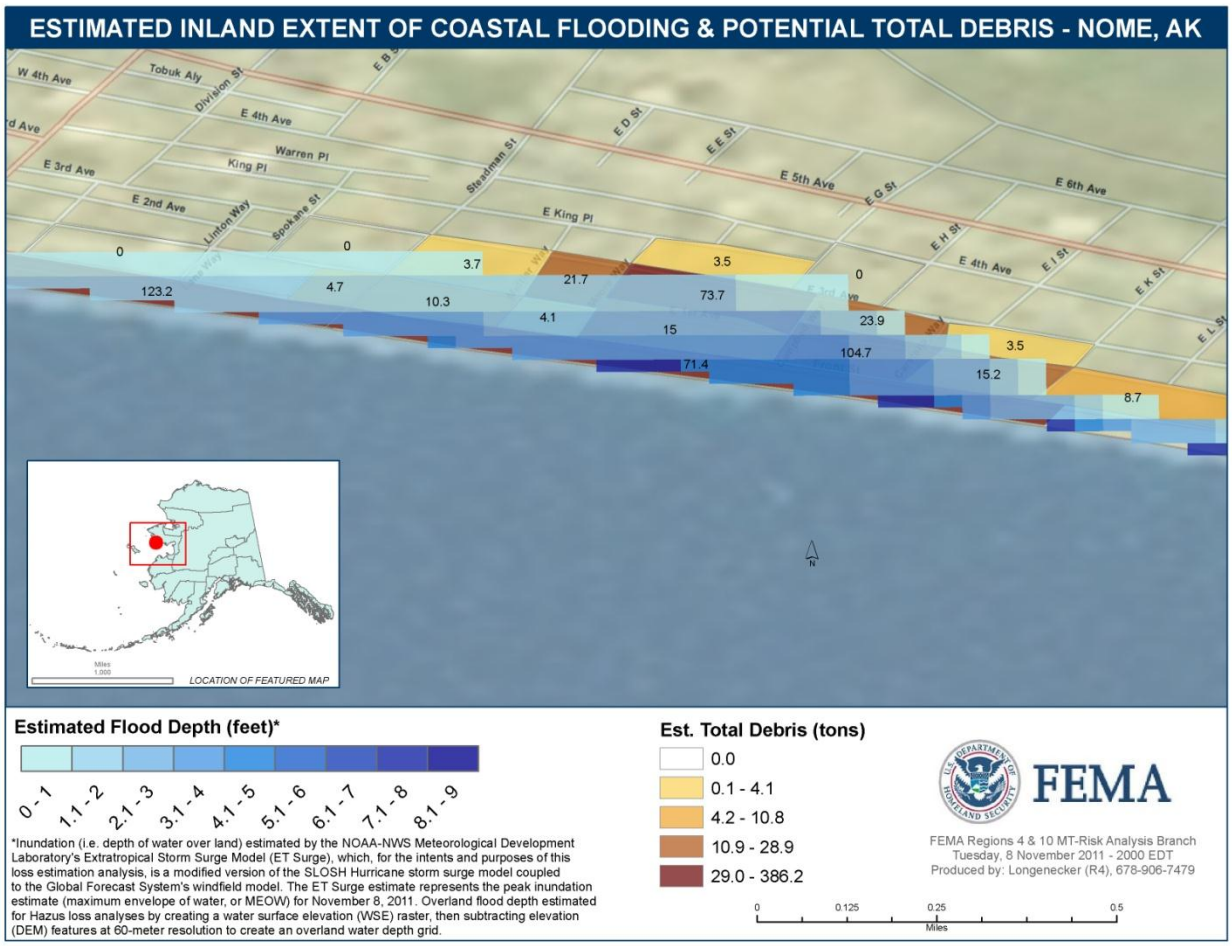
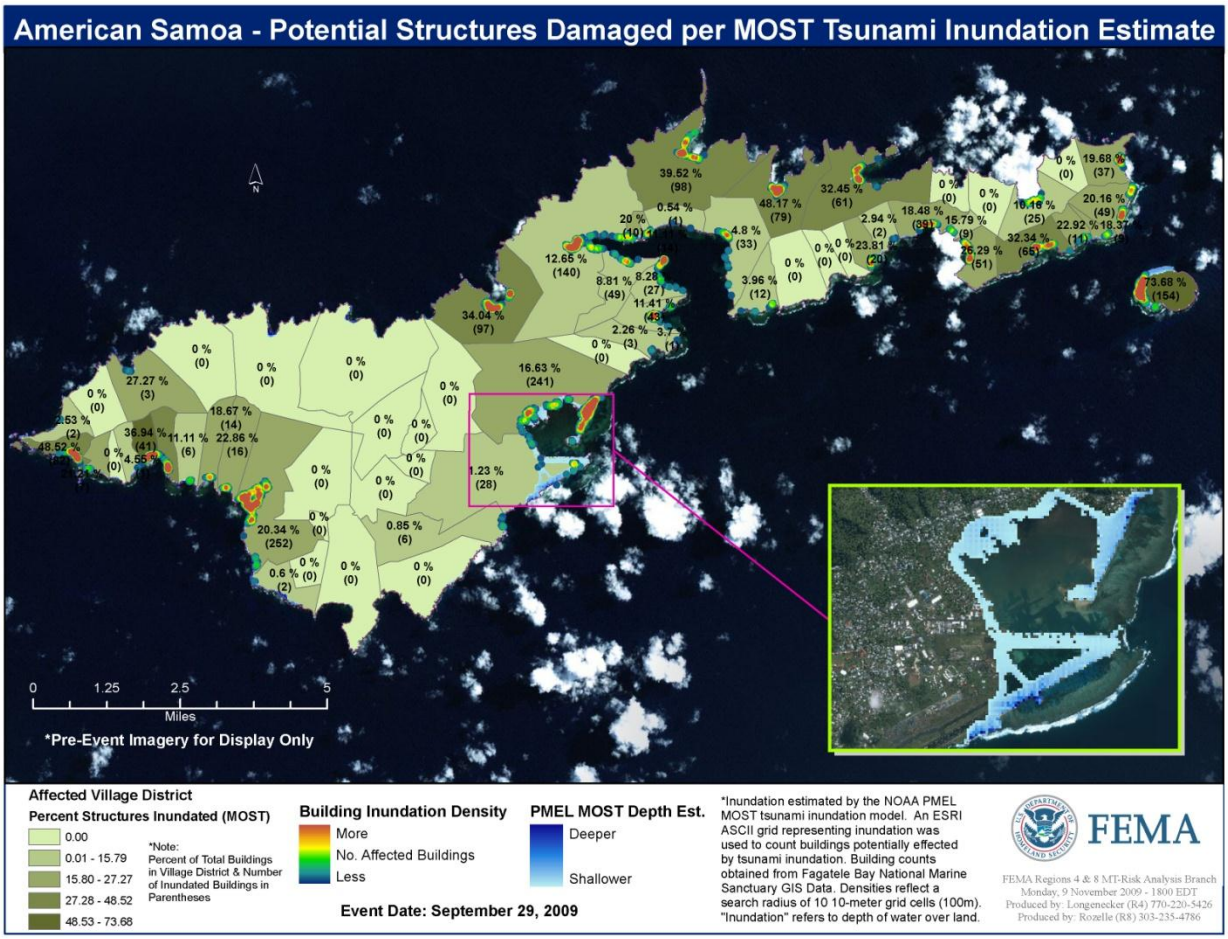


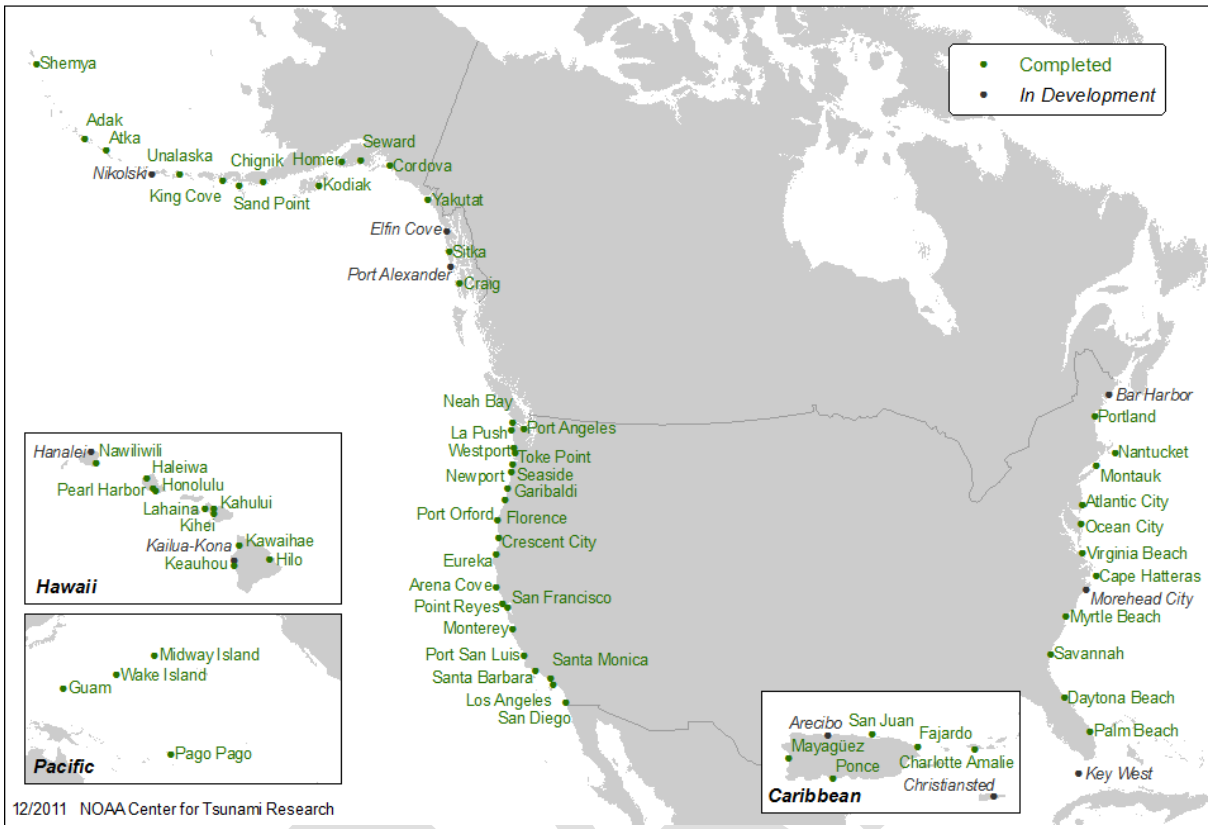
Figure 63. Estimated inland extent of coastal flooding and potential total debris - Nome, AK.

Tsunami Inundation Analysis[F2]

With the impending release of the Hazus Tsunami model in 2013, the Risk Analysis Team has been able to successfully evolve the Coastal Flood Loss Methodology into a Tsunami inundation depth grid.


American Samoa - Potential Structures Damaged per MOST Tsunami Inundation Estimate
N
0 1.25 2.5 5
Miles
*Pre-Event Imagery for Display Only
Affected Village District
Percent Structures Inundated (MOST)
0.00
0.01 - 15.79
15.80 - 27.27
27.28 - 48.52
48.53 - 73.68
*Note:
Percent of Total Buildings in Village District & Number of Inundated Buildings in Parentheses
Building Inundation Density
More
No. Affected Buildings
Less
PMEL MOST Depth Est.
Deeper
Shallower
Event Date: September 29, 2009
*Inundation estimated by the NOAA PMEL MOST tsunami inundation model. An ESRI ASCII grid representing inundation was used to count buildings potentially effected by tsunami inundation. Building counts obtained from Fagatele Bay National Marine Sanctuary GIS Data. Densities reflect a search radius of 10 10-meter grid cells (100m). "Inundation" refers to depth of water over land.
FEMA
FEMA Regions 4 & 8 MT-Risk Analysis Branch
Monday, 9 November 2009 - 1800 EDT
Produced by: Longenecker (R4) 770-220-5426
Produced by: Rozelle (R8) 303-235-4786

NOAA Tsunami Forecast Models



Appendix E: Planning Assumptions

Within the United States, flooding, coastal and riverine, tropical and extratropical system included, is generally regarded as the deadliest natural hazard. The development of the coastal flood methodology was developed as a partnership between the FEMA Region IV Hurricane Program and FEMA Region IV Mitigation GIS to create prepackaged data for quick delivery to the Operations Section in the RRCC. Appendix G: Attribute Reference Guide lists and defines each attribute in the CFLA. It is important to note that all estimates found in the CFLA are ONLY related to storm surge. Wind is not accounted for in the Coastal Flood Loss Atlas.

Add more planning assumptions[F3].

DRAFT

Appendix F: CFLA Limitations

When considering the use of the Coastal Flood Loss Atlas for pre-disaster mitigation or disaster operations use, there are several limitations that must be considered. The CFLA only take storm surge flooding into consideration, thus all property damage estimates, shelter needs, and population displacement values **DO NOT** include any wind-related or inland flooding estimates. When using the CFLA in conjunction with Hazus Hurricane Wind estimates, the user must account for the fact that both estimates can include the same damages.

> **NOTE:** The CFLA version 3.0 was created using Hazus-MH MR4, using the Coastal Flood Model. In recent versions of Hazus (2.0+), users can produce damage estimates using by coupling the wind and coastal flood model, which incorporates SLOSH and SWAN model data as well as storm track data. This in turn produces estimates accounting for both wind and surge.

All analysis in the CFLA has been completed at the census block, however for data display purposes; the CFLA was completed at the county-level. All of the Hazus Packaged Regions (HPRs) were archived after completions, and each county has a corresponding HPR. Therefore, the data can be downscaled on an individual county basis.

The final limitation is found within the base data used in all Hazus modeling. Census data and figures are quoted from the 2000 US Census. Although new census data has been turned out, the geographies of the data have not been computed, and were not available at the time of the completion of the CFLA. Since the CFLA is a general estimate of loss, it relies on the stock building data found in Hazus.

DRAFT

Appendix G: Attribute Reference Guide

This appendix outlines all of the attributes in the Coastal Flood Loss Atlas.

1. **CountyName** – Name of the county
2. **NumTracts** – Number of census tracks in the county
3. **SHAPE_AREA** – Feature geometry
4. **COUNTYFIPS** – FIPS code for the county
5. **State** – State in which the county is located
6. **StateFips** – FIPS code for the state in which the county is located
7. **FEMA_REG** – FEMA region in which the county is located
8. **SLOSHBASIN** – SLOSH basin that was used to create the depth grid and boundary
9. **POP2000** – US Census population 2002 for the county
10. **AREA_MI** – Area of the county in square miles
11. **HZ_TOTBLDG** – Hazus building count in county
12. **HZ_BLDGVAL** – Hazus total value of buildings in county in millions of dollars
13. **HZ_PCT_RES** – Hazus percent of buildings in the county that are residential
14. **HZ_RESEXPO1000** – Hazus residential building value exposure in thousands of dollars
15. **E_HOSPBEDS** – Hazus number of hospital beds in the county
16. **C#_RSUBDMG** – Hazus percentage of residential structures substantially damaged in the county for each category or storm surge
17. **C#_SUBFIRE** – Hazus number of fire stations substantially damaged in the county for each category or storm surge
18. **C#_SUBHOSP** – Hazus number of hospitals substantially damaged in the county for each category or storm surge
19. **C#_SUBPOL** – Hazus number of police stations substantially damaged in the county for each category or storm surge
20. **C#_SUBSCHL** – Hazus number of schools substantially damaged in the county for each category or storm surge
21. **C#_DEBTONS** – Hazus amount of debris in ton in the county generated by each category of storm surge
22. **C#_DEBTL** – Hazus amount of debris in truck loads (1 truck load = 25 tons) in the county generated by each category of storm surge
23. **C#_DISPHH** – Hazus number of displaced households in the county for each category of storm surge
24. **C#_DISPPOP** – Estimated displaced population in the county for each category of storm surge
25. **C#_SHELPOP** – Hazus estimated short term shelter population in the county for each category of storm surge
26. **C#_PCTSTS** – Percentage of short term shelter population (C#_SHELPOP) based on total displaced households (C#_DISPHH) in the county for each category of storm surge
27. **C#PCTCOPOP** – percentage of short term shelter population (C#_SHELPOP) in the county per the county's population (pop2000) for each category of storm surge
28. **C#LPCT_TRV** – Hazus percentage of building loss per total replacement value in the county for each category of storm surge
29. **C#_BLDG_LR** – Hazus building loss ratio in the county for each category of storm surge
30. **CstBdgDgC#** – Hazus total building damages cost in county for each category of storm surge

DRAFT

31. **PerCapLosC#** – Total building damages cost (CstBdgDgC#) per county population (pop2000) for each category of storm surge
32. **MR2_C#_BLR** –HAZUS MH-MR2 (from CFLAv1) building loss ratio in the county for each category of storm surge
33. **Max_Srg_C#** – Maximum estimated inland flooding for category of storm surge
34. **WE_Rank** – Rank of counties from west to east then south to north (Texas to Maine)

DRAFT

Appendix H: Exercise Use

The Coastal Flood Loss Atlas version 3 has been used in exercises at all levels of government, and since March 2012 the Risk Analysis Team has supported exercises for the following external agencies;

1. International Association of Emergency Managers (IAEM) – Interstate exercise focusing on a landfalling hurricane in Horry/Georgetown Counties in South Carolina. This location was chosen based on its ability to involve multiple states and multiple agency.
2. Georgia Emergency Management Agency (GEMA) – State level exercise for Hurricane Jerry 2012. This scenario is used as an example below.
3. Savannah Area GIS (SAGIS) – Chatham County and the City of Savannah in Georgia the CFLA to understand the potential losses from a category 3 hurricane making landfall in their county. They incorporated their data into their annual Hurricane exercise

Below is an example of how the CFLA can be used in an exercise. This example was brought together for GEMA focusing on a landfalling hurricane in Chatham County Georgia.

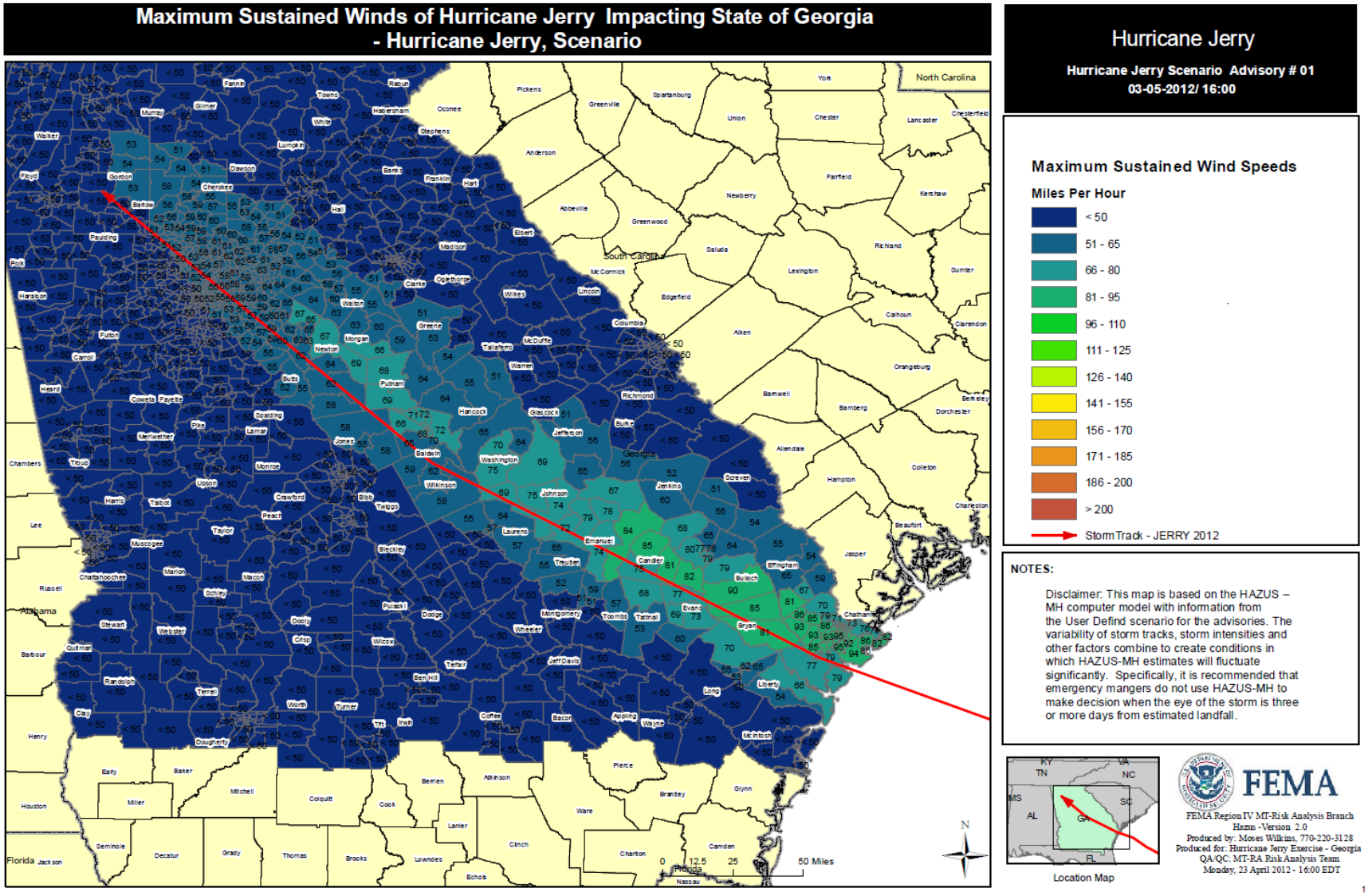


Figure 64. Maximum Sustained Winds of Hurricane Jerry Impacting Georgia.

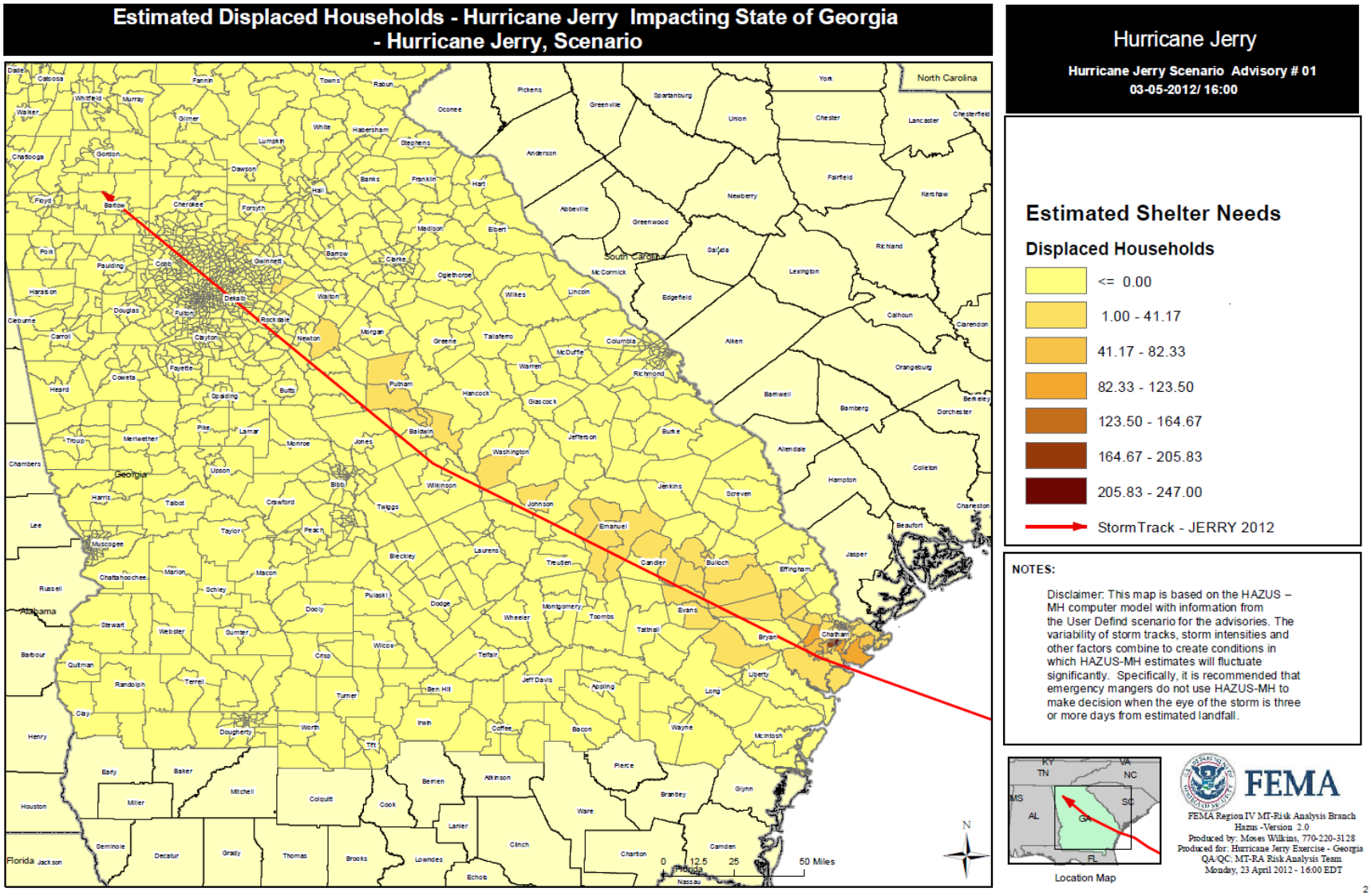


Figure 65. Estimated Displaced Households for Hurricane Jerry in Georgia.

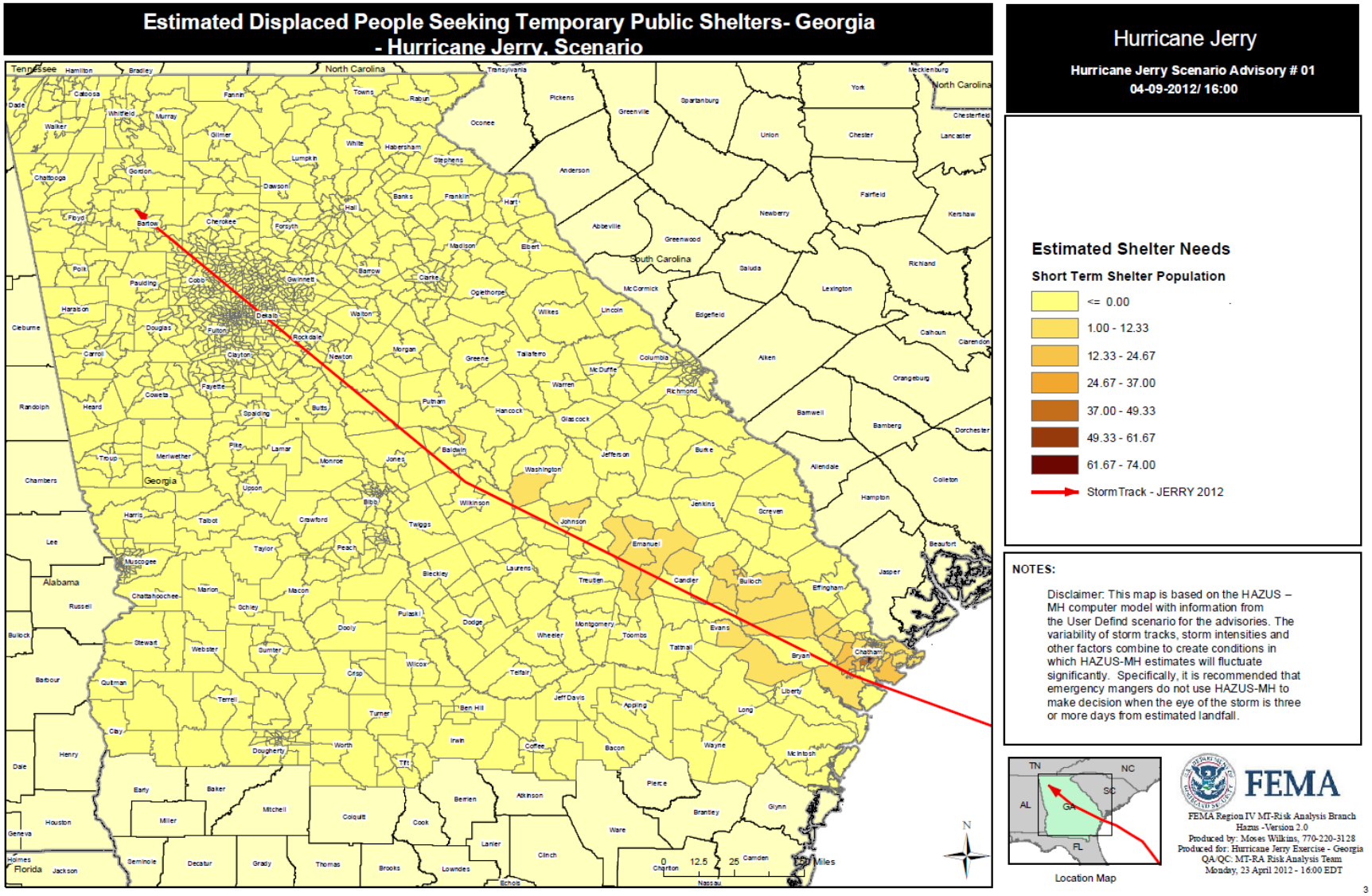


Figure 66. Estimated Displaced People Seeking Temporary Public Shelter for Hurricane Jerry in Georgia.

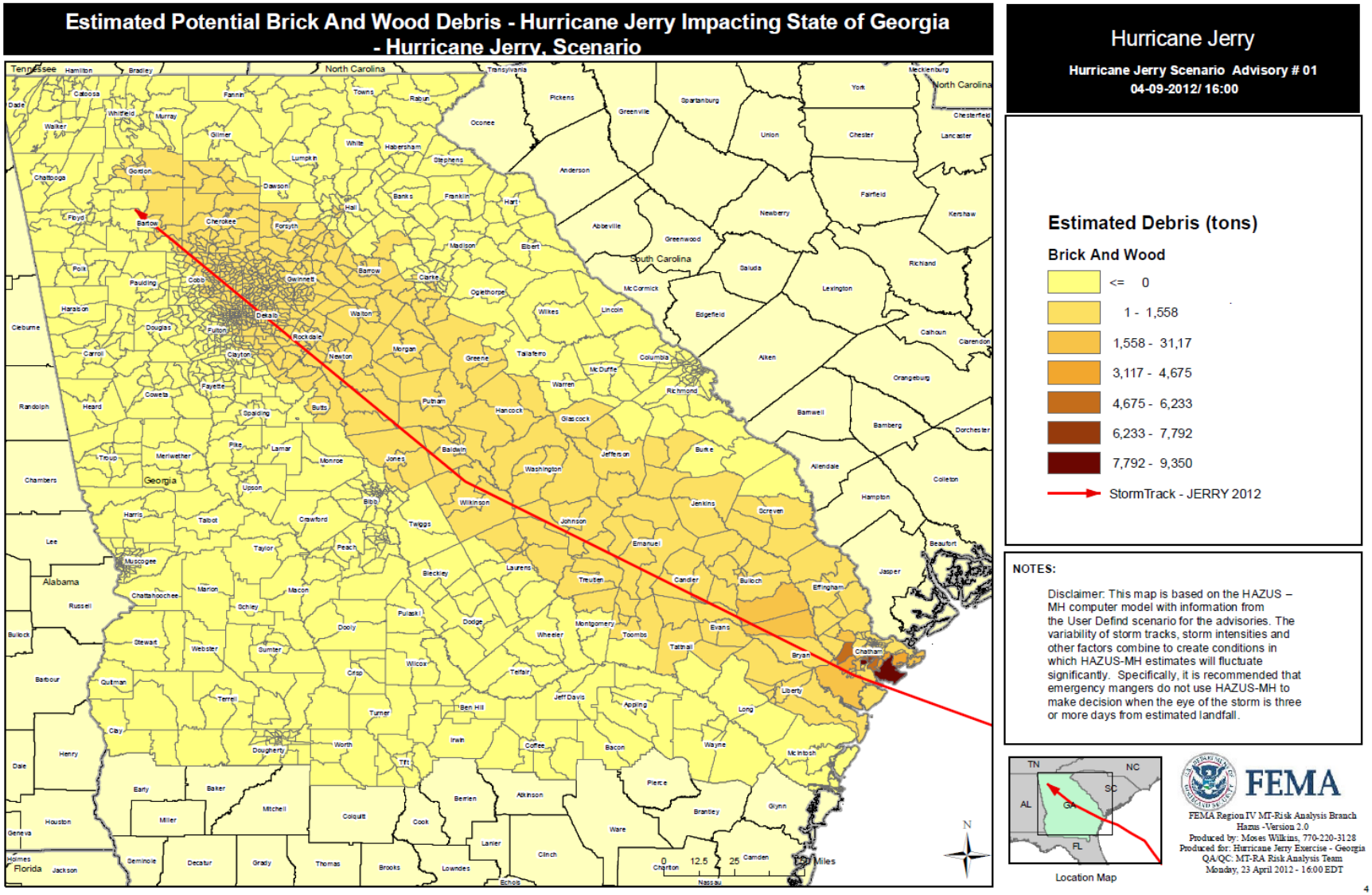


Figure 67. Estimated Potential Brick and Wood Debris for Hurricane Jerry in Georgia.

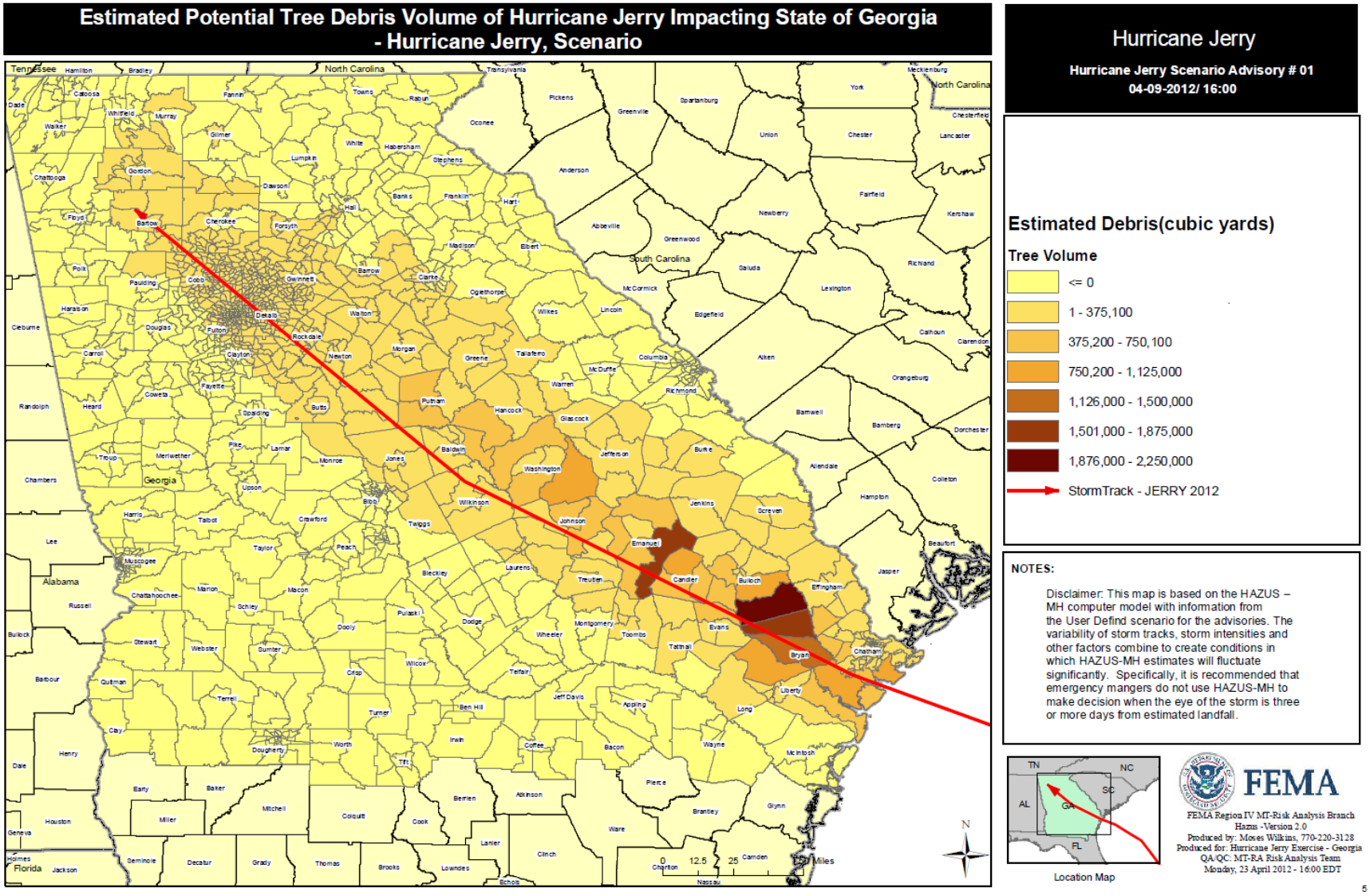


Figure 68. Estimated Potential Tree Debris for Hurricane Jerry in Georgia.

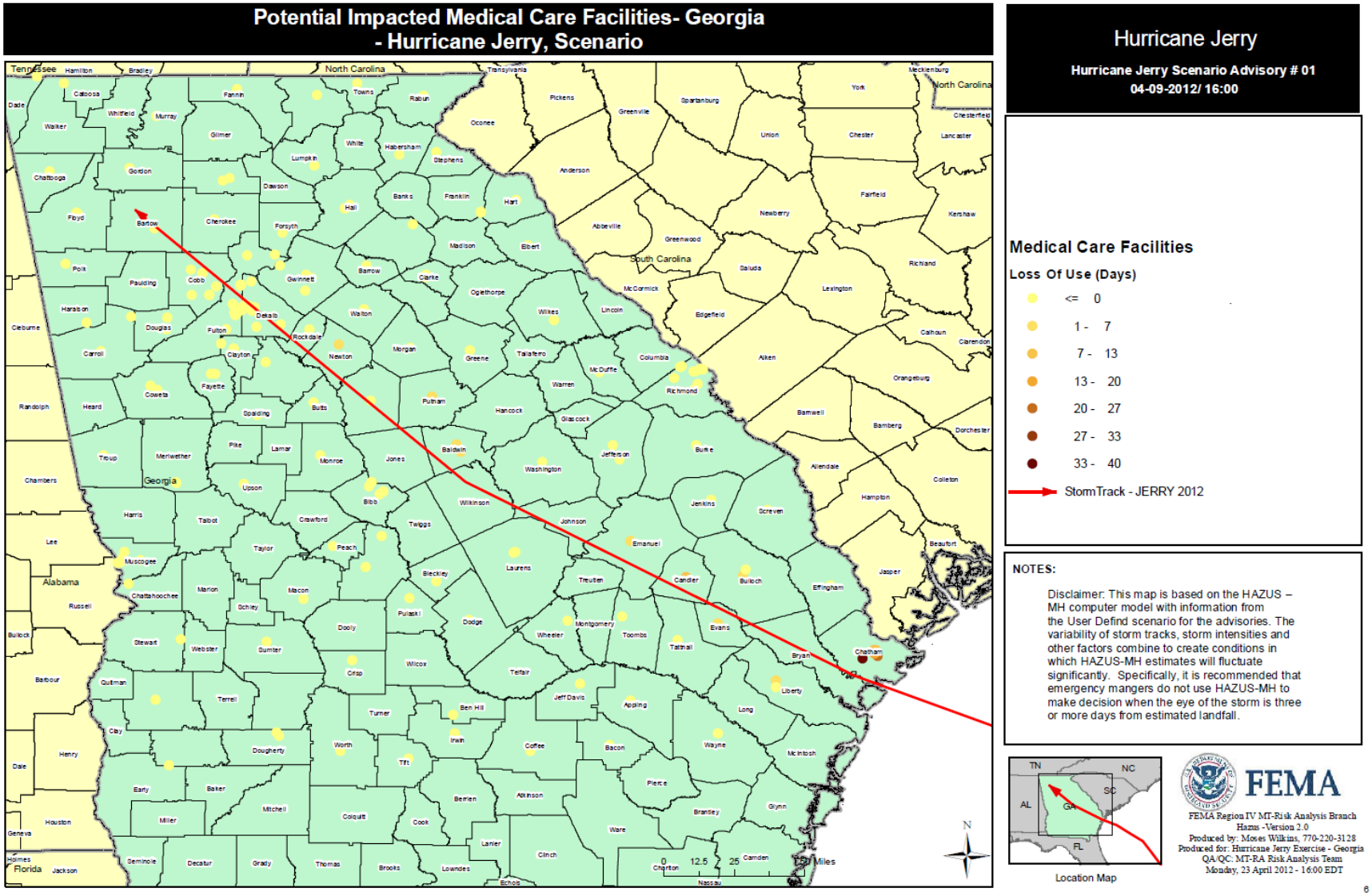


Figure 69. Potential Impacted Medical Care Facilities for Hurricane Jerry in Georgia.

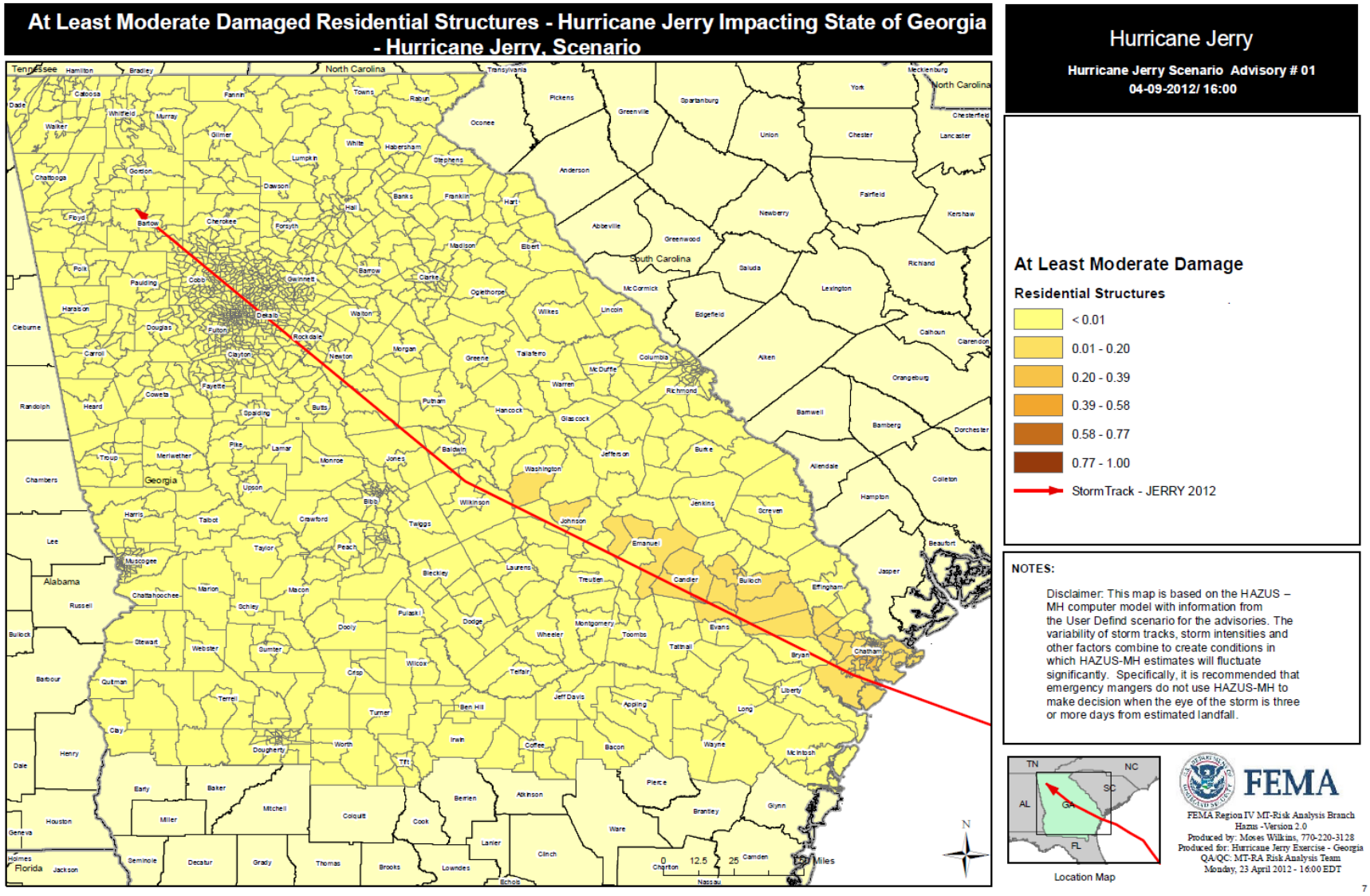


Figure 70. At Least Moderate Damage to Residential Structures for Hurricane Jerry in Georgia.

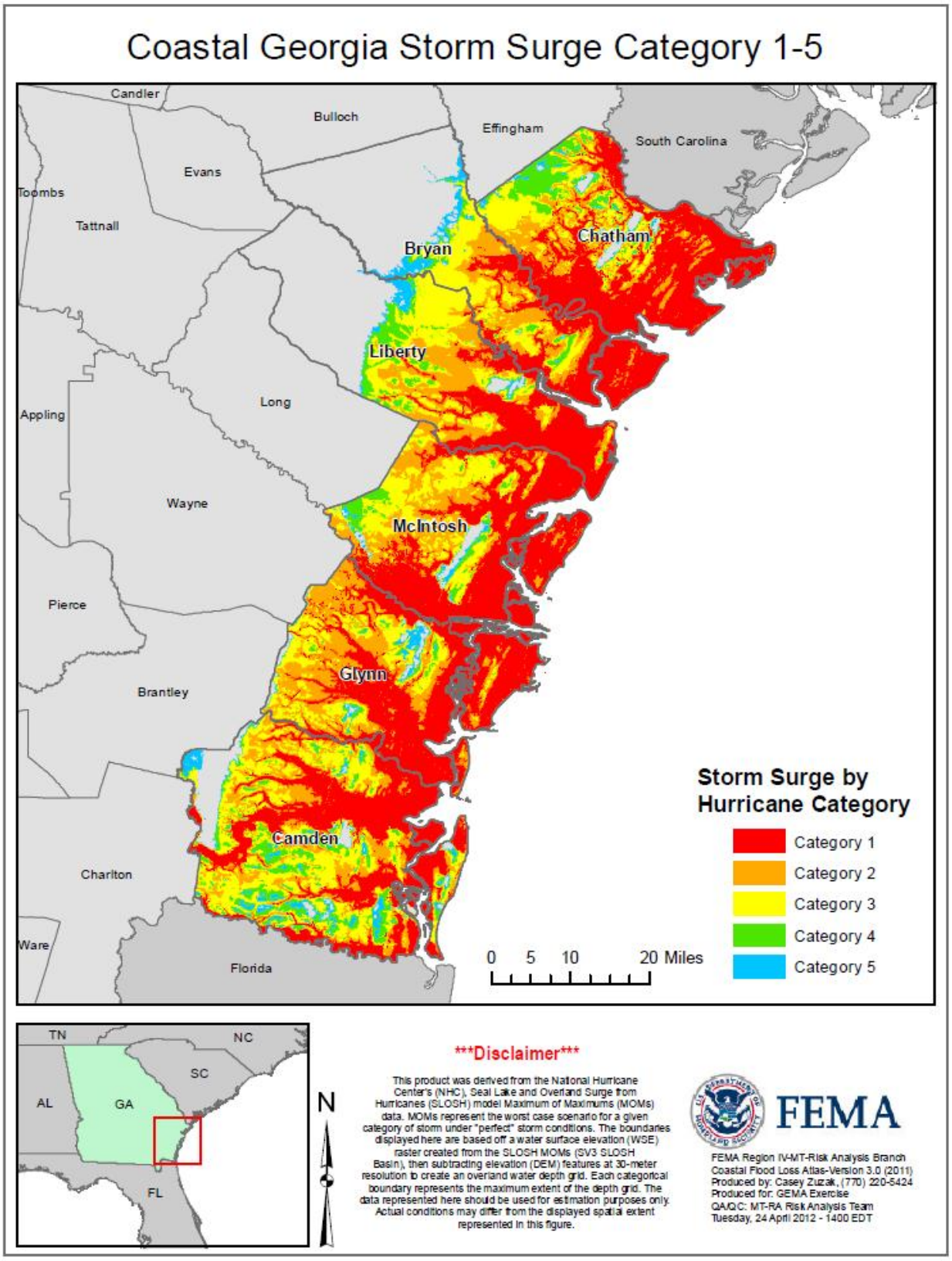


Figure 71. Category 1-5 Storm Surge Inundation Boundaries for Coastal Georgia.

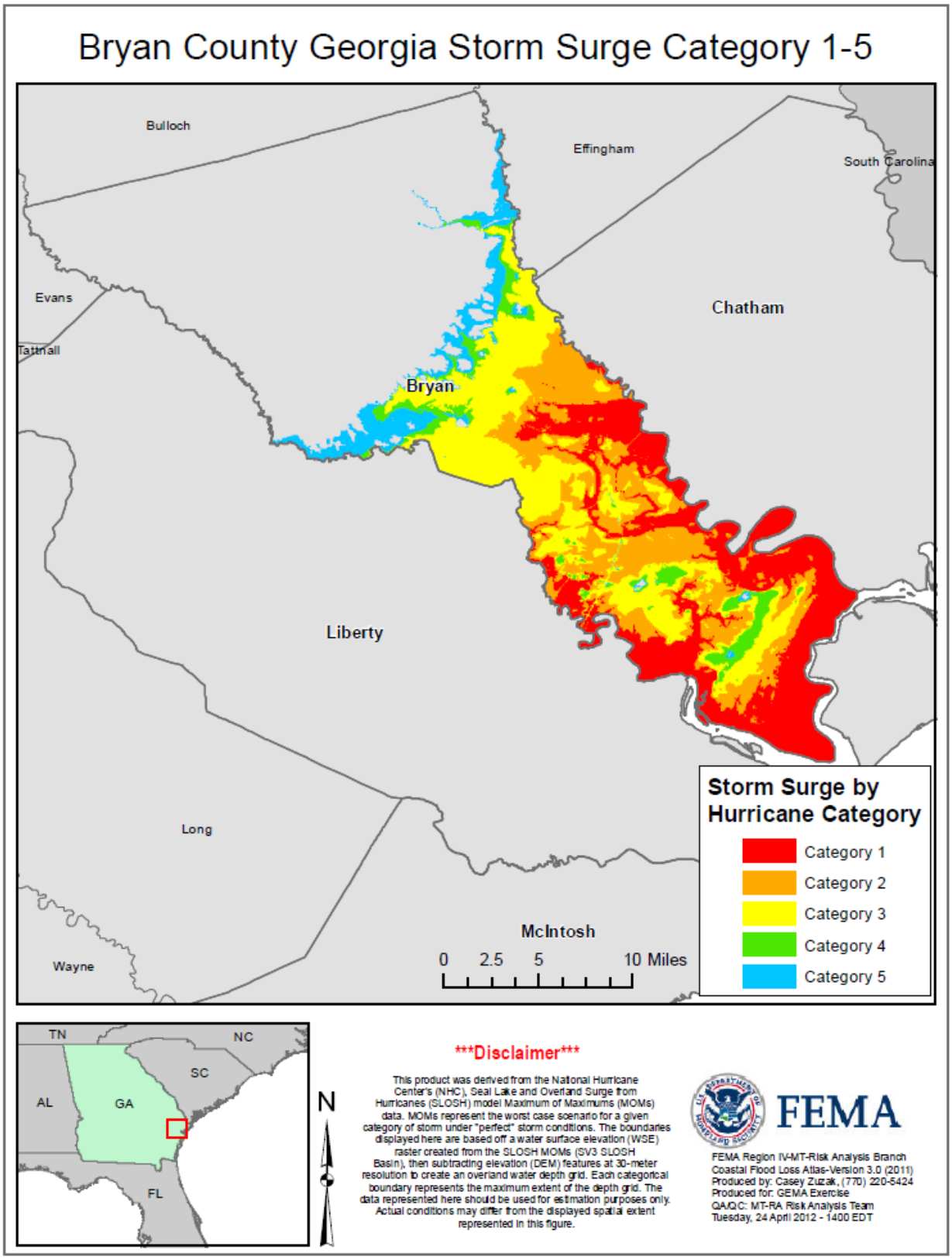
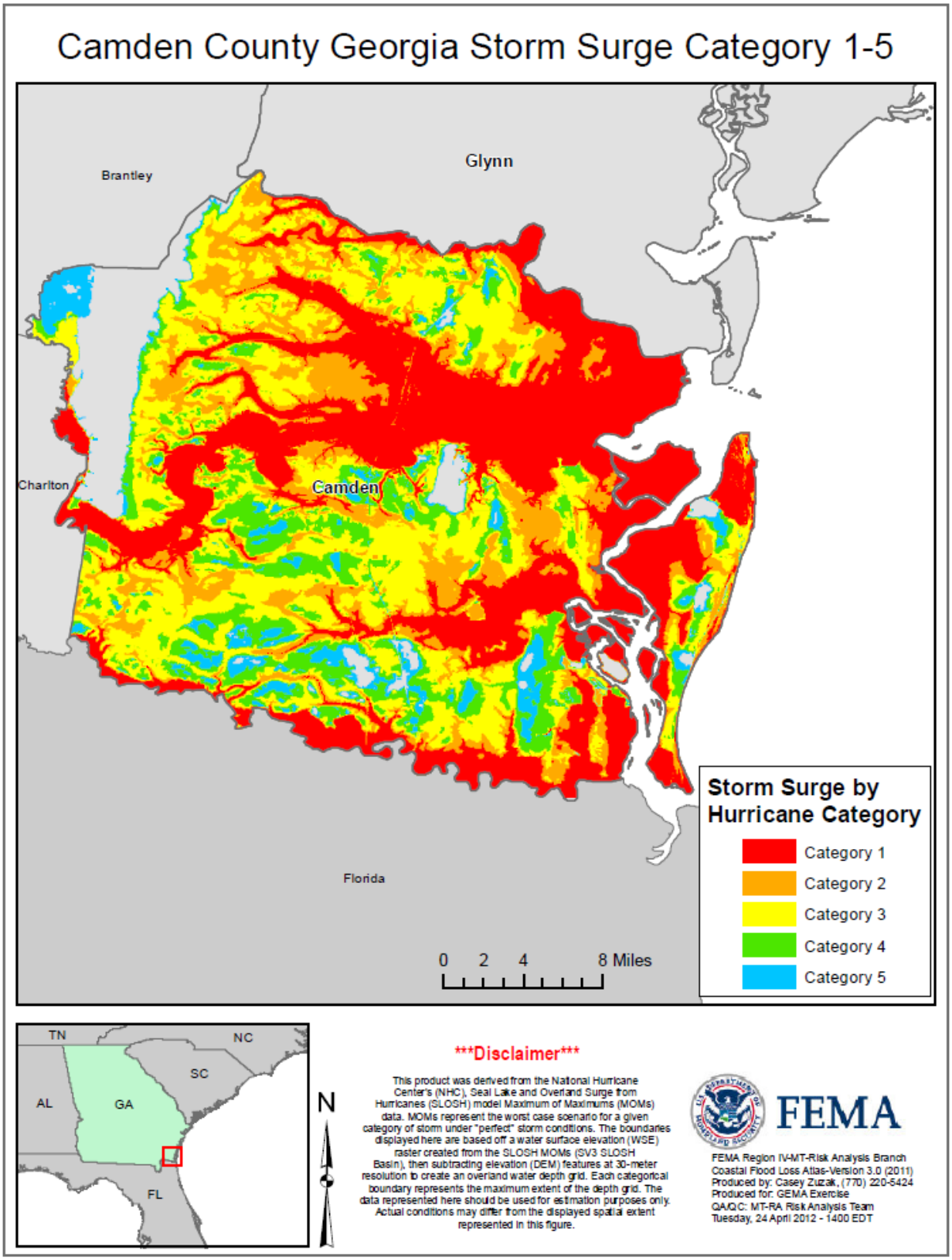
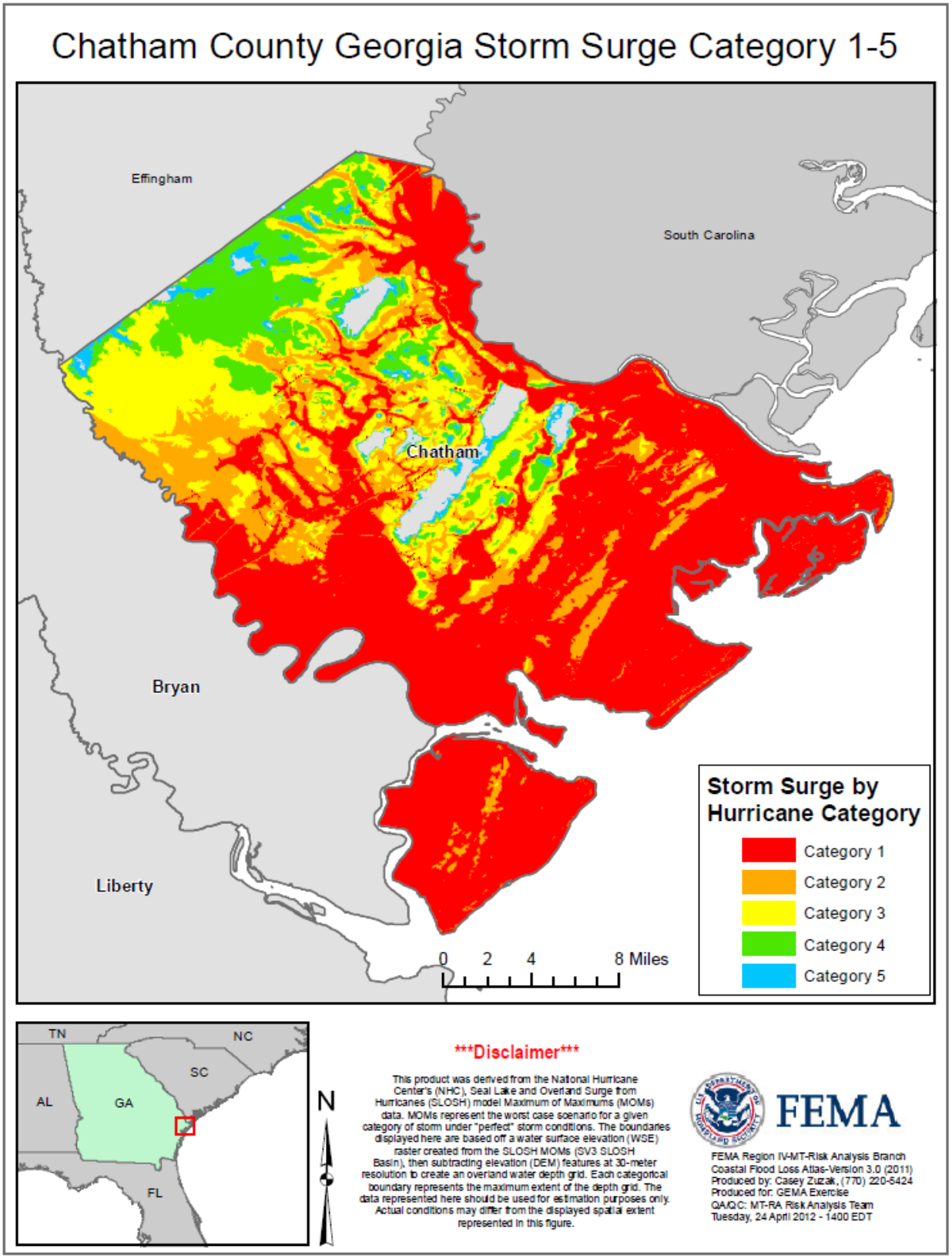


Figure 72. Category 1-5 Storm Surge Inundation Boundaries for Bryan County, Georgia.



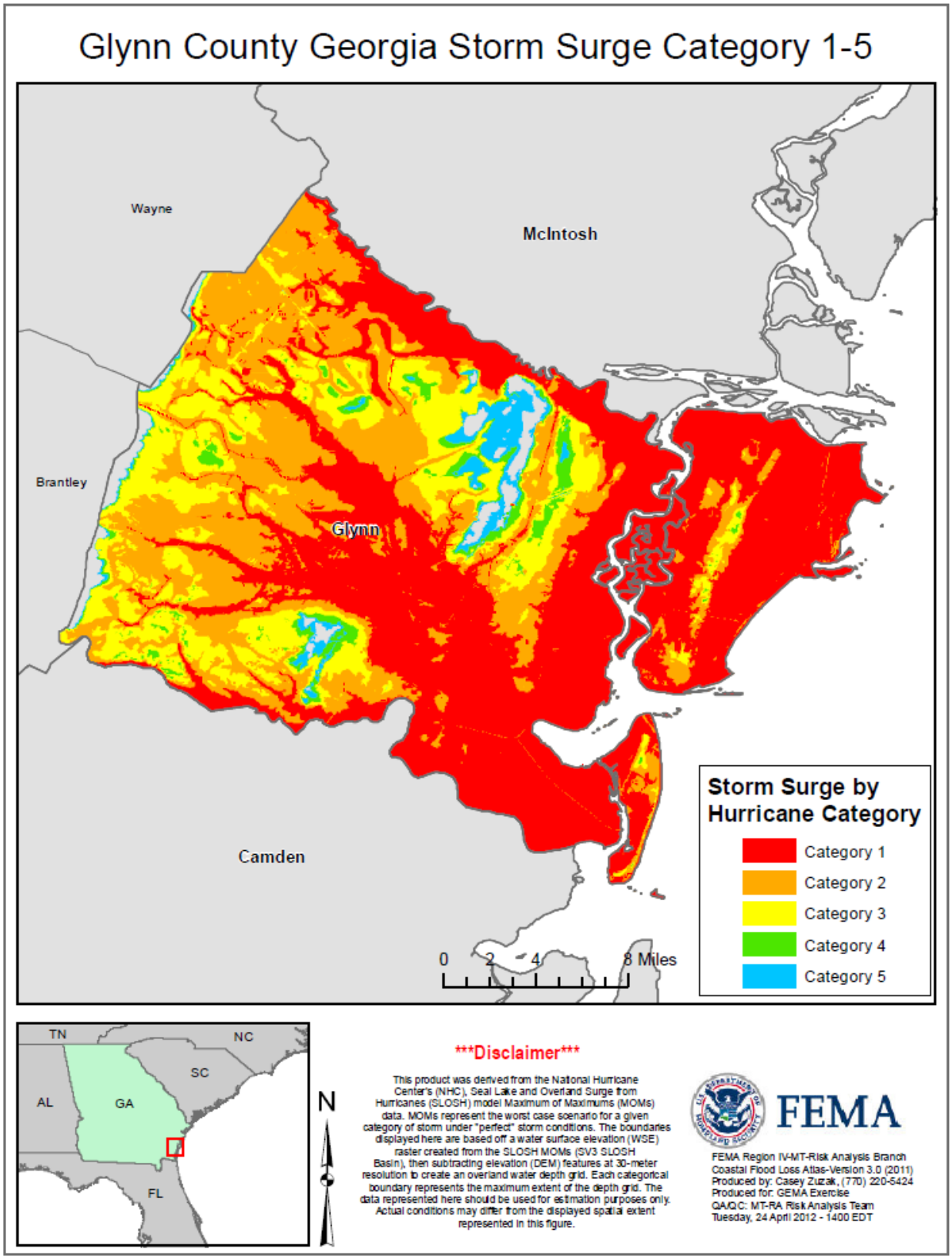
10

Figure 73. Category 1-5 Storm Surge Inundation Boundaries for Camden County, Georgia.



11

Figure 74. Category 1-5 Storm Surge Inundation Boundaries for Chatham County, Georgia.



12

Figure 75. Category 1-5 Storm Surge Inundation Boundaries for Glynn County, Georgia.

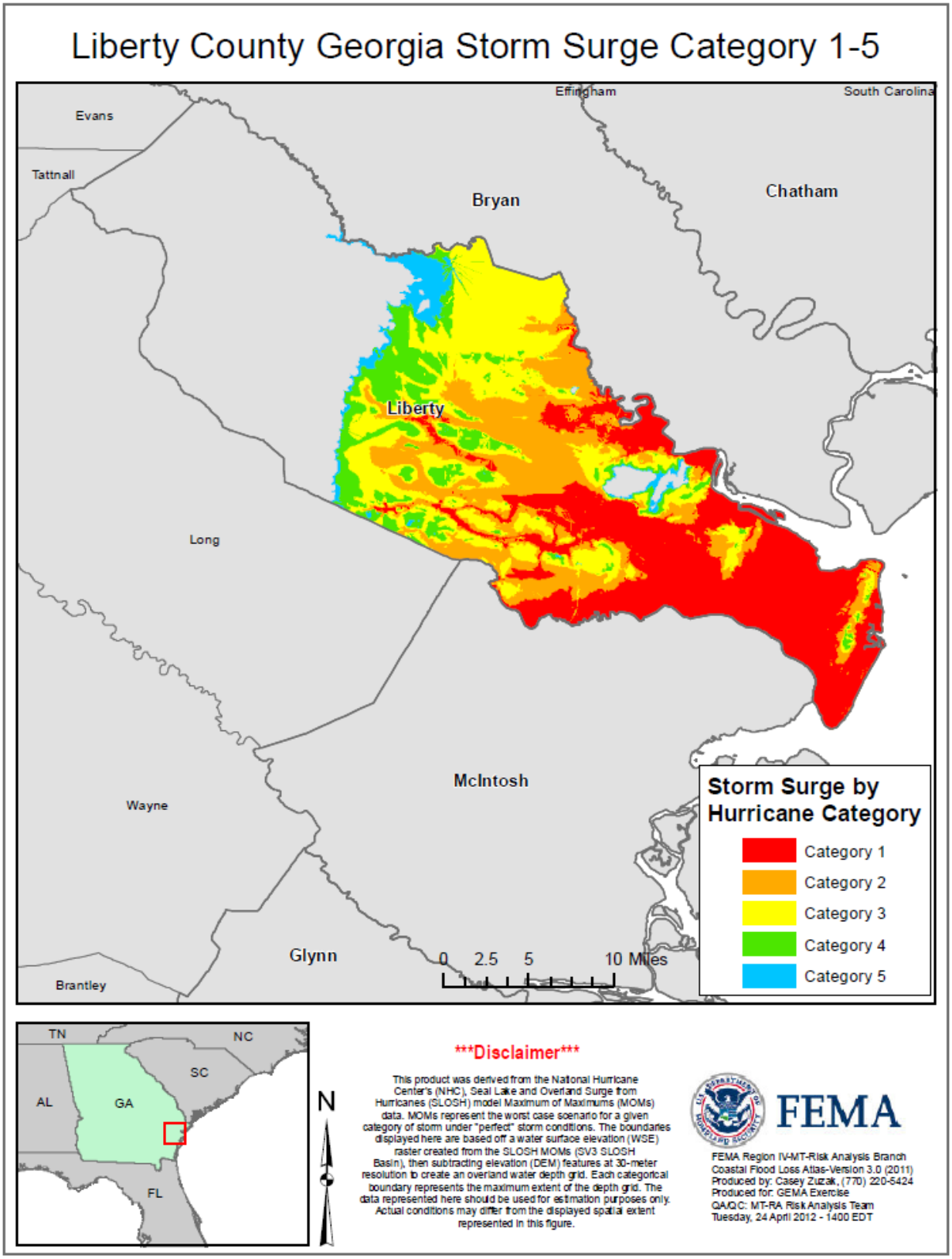


Figure 76. Category 1-5 Storm Surge Inundation Boundaries for Liberty County, Georgia.

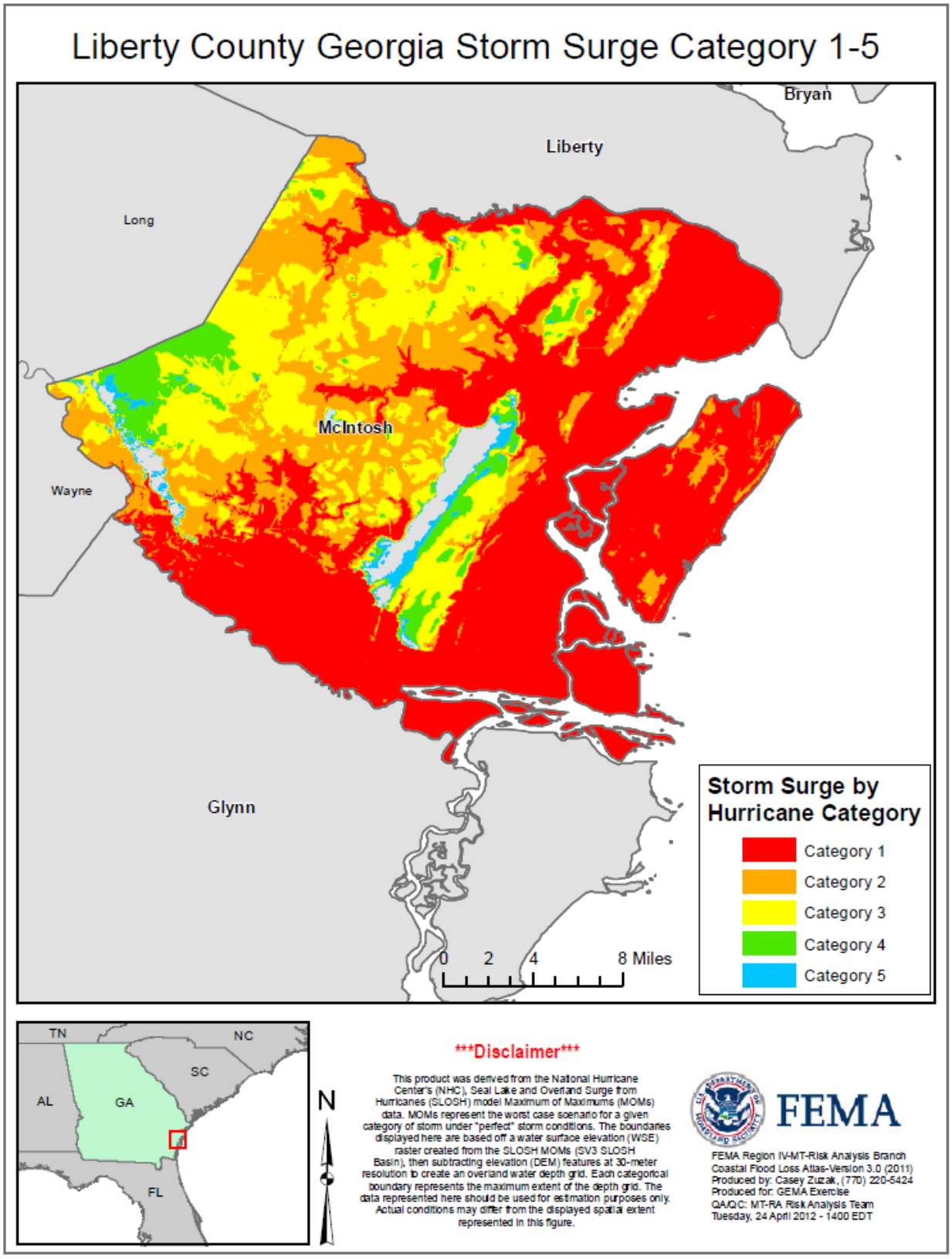


Figure 77. Category 1-5 Storm Surge Inundation Boundaries for McIntosh County, Georgia.

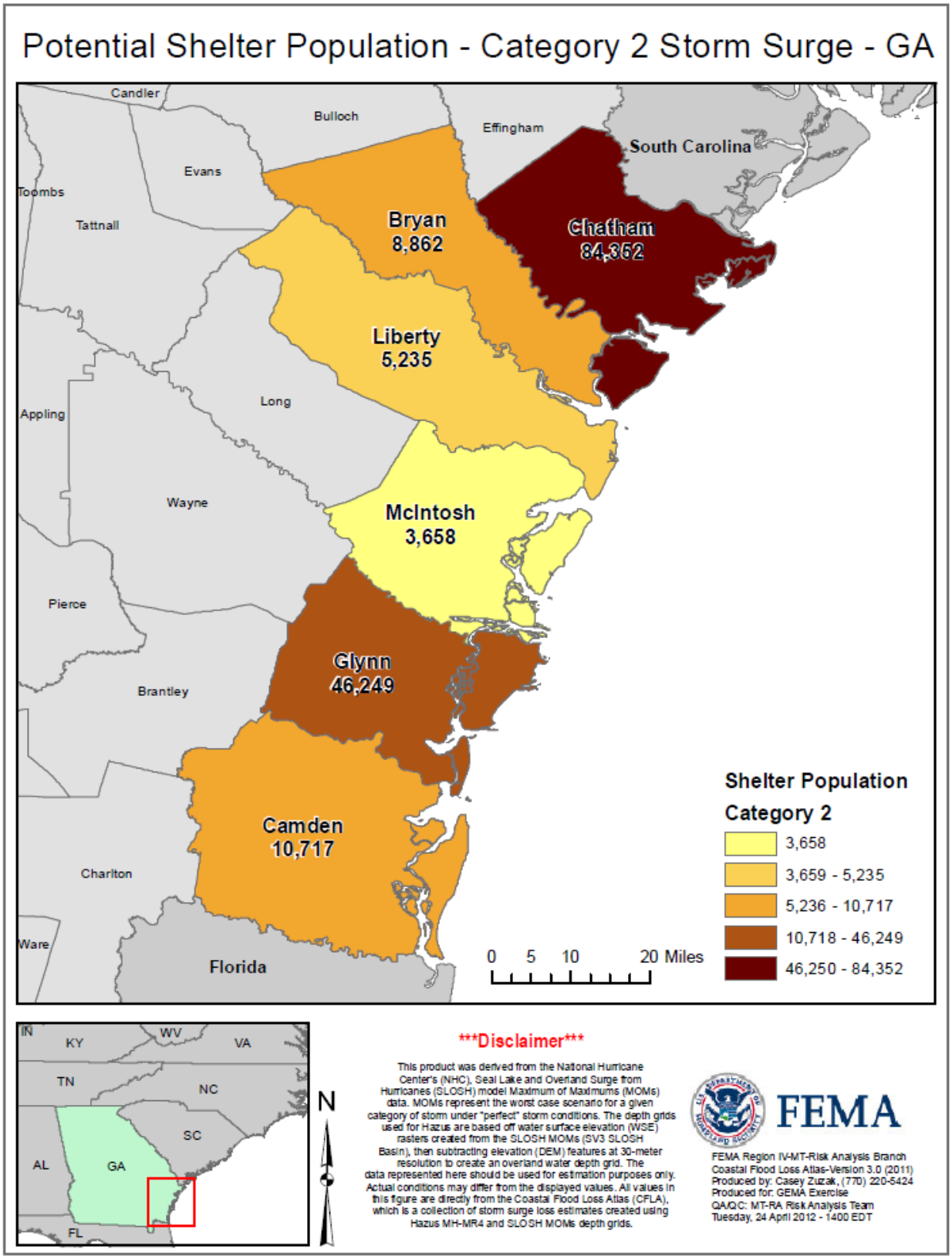


Figure 78. Potential Shelter Population for a Category 2 Storm Surge in Coastal Georgia.

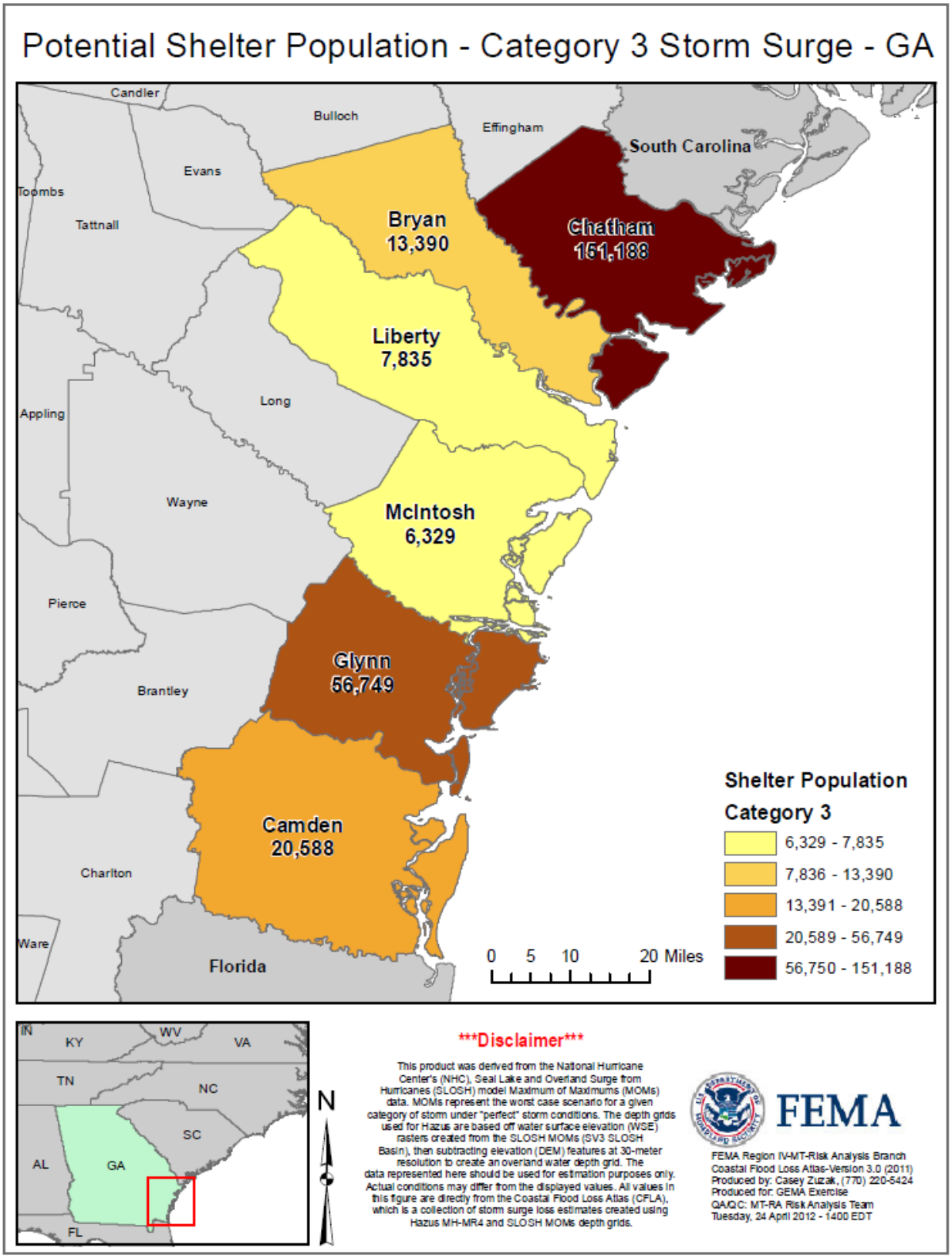
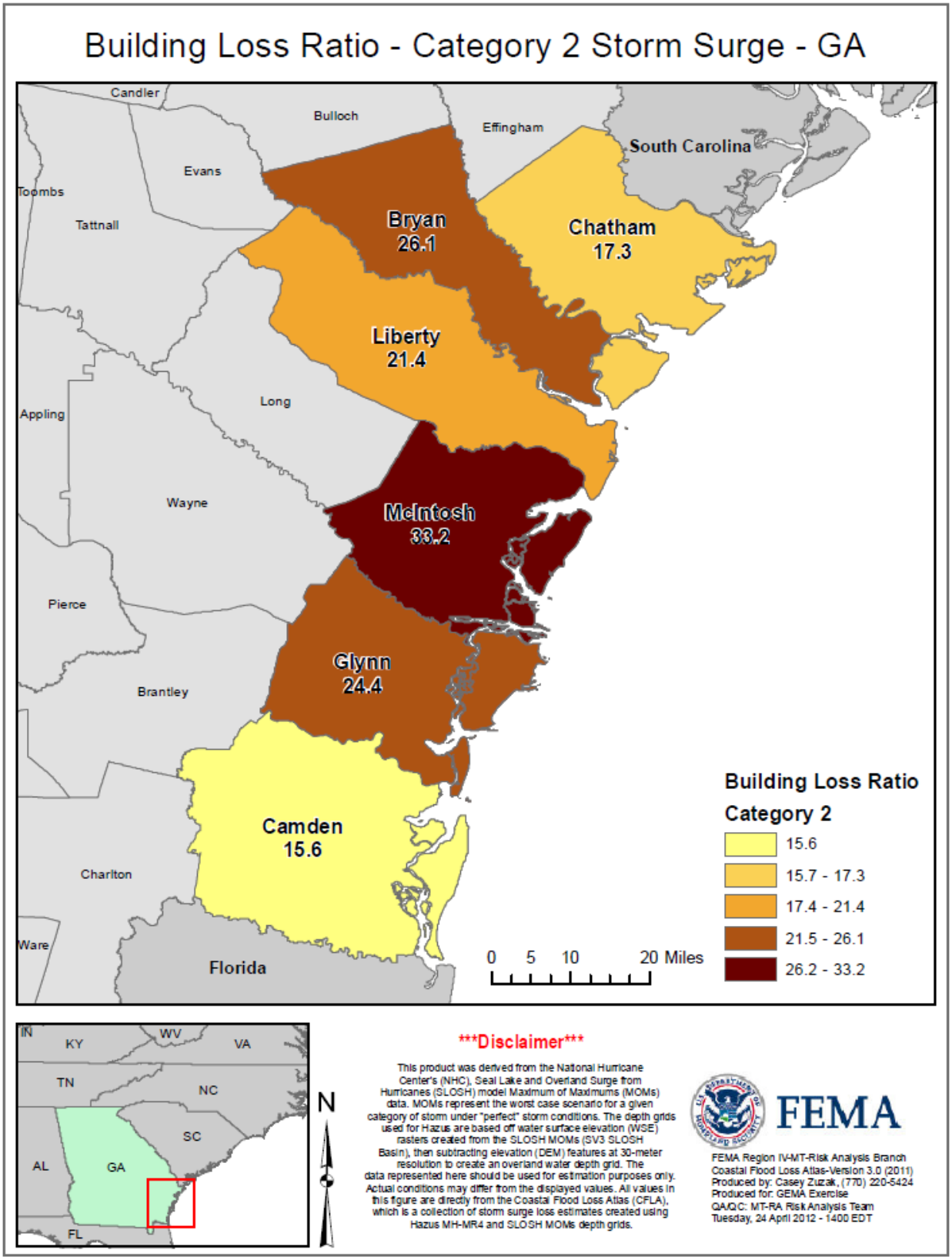


Figure 79. Potential Shelter Population for a Category 3 Storm Surge in Coastal Georgia.



17

Figure 80. Building Loss Ratio for a Category 2 Storm Surge in Coastal Georgia.

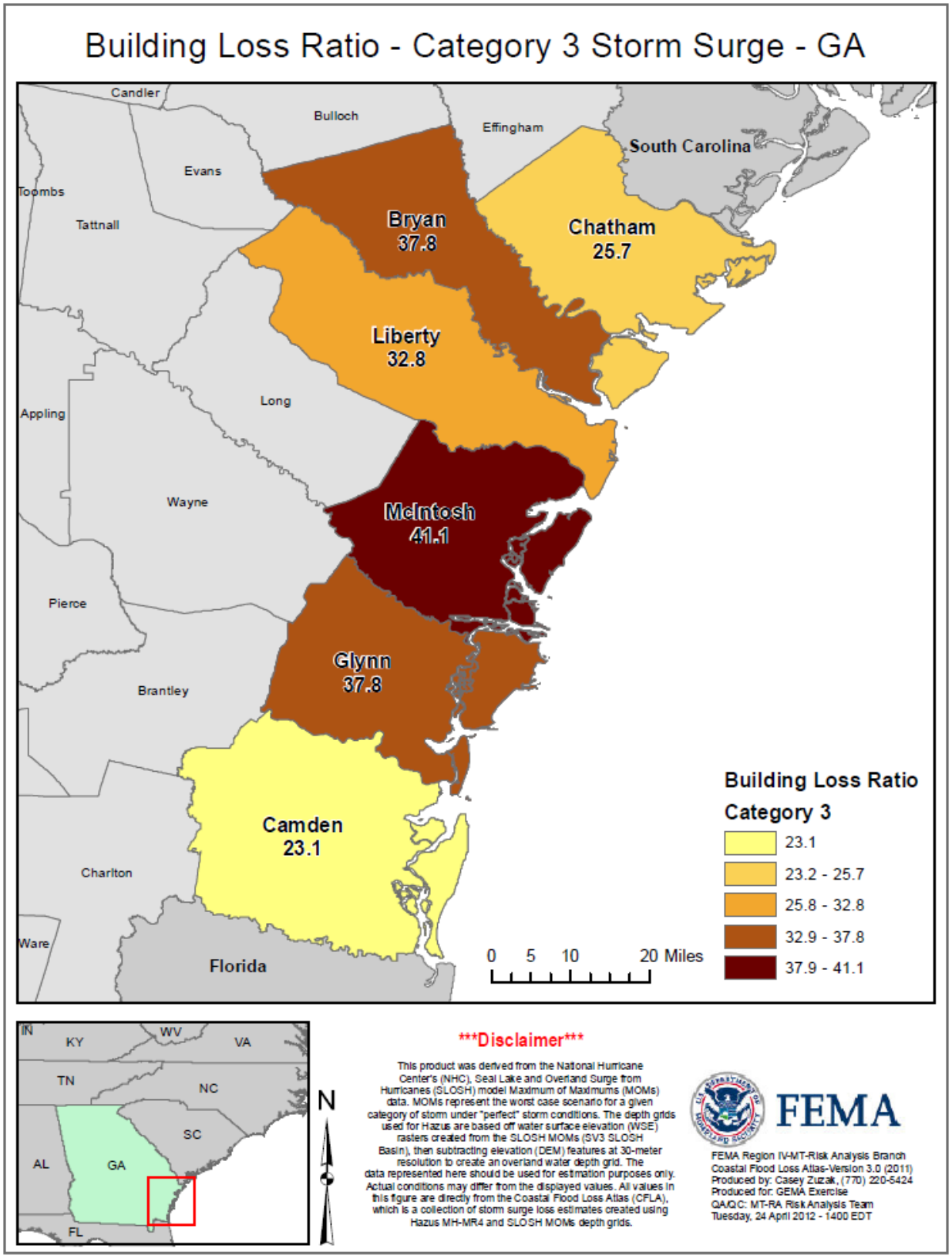


Figure 81. Building Loss Ratio for a Category 3 Storm Surge in Coastal Georgia.

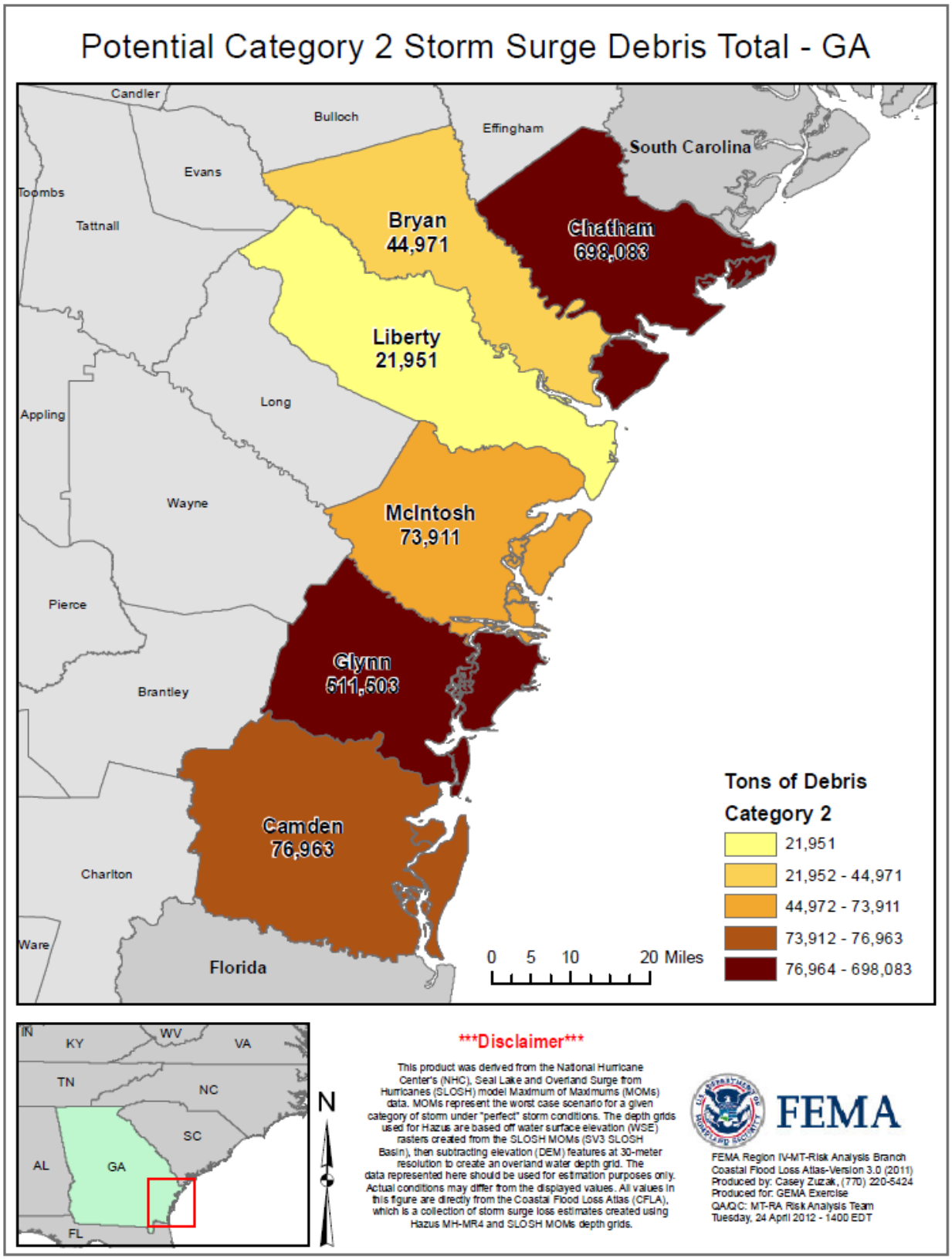
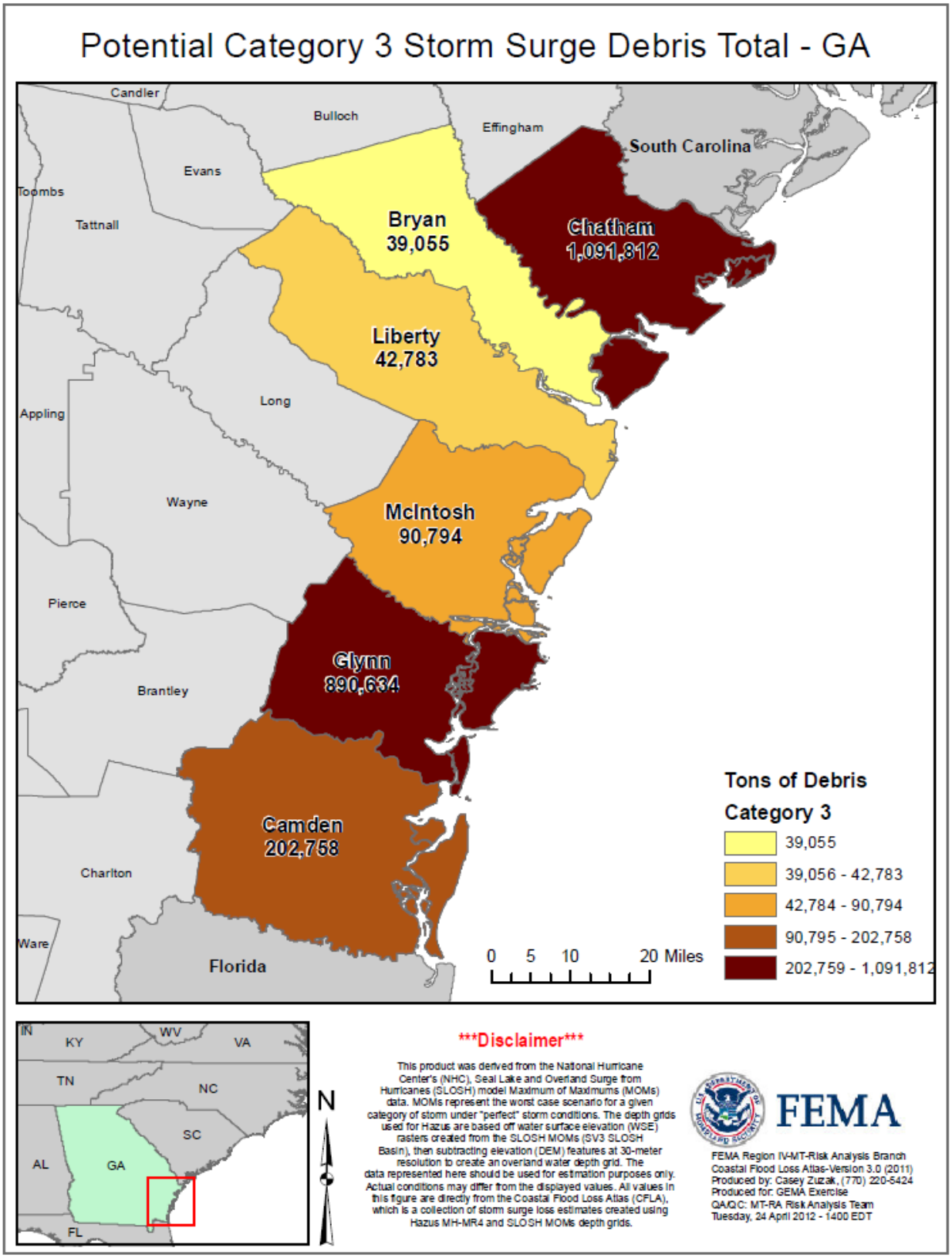


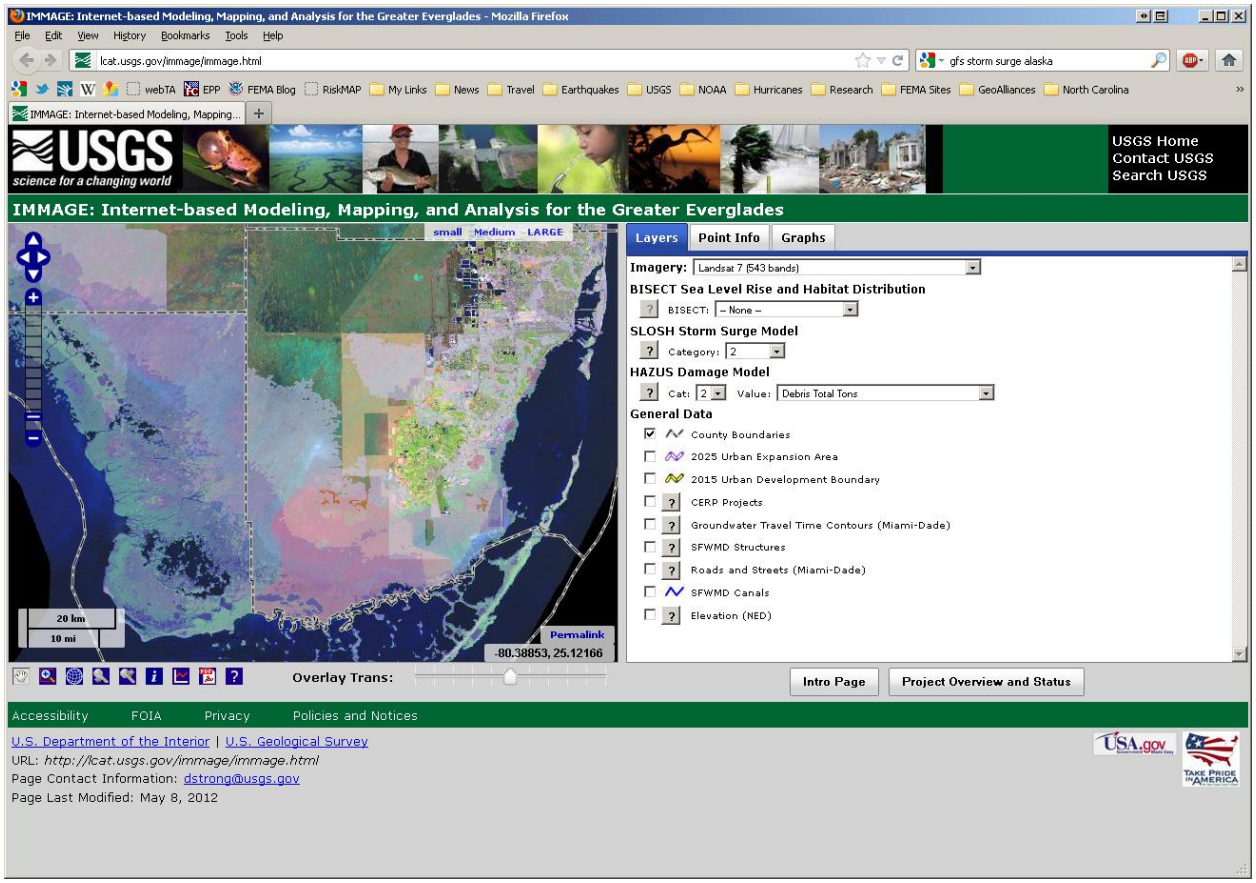
Figure 82. Estimated Debris Total for a Category 2 Storm Surge in Coastal Georgia.



20

Figure 83. Estimated Debris Total for a Category 3 Storm Surge in Coastal Georgia.

Appendix I: FEMA & USGS IMMAGE Project[F4]



List of Figures[F5]

Figure 1. Sample file management. vi

Figure 2. Disk space usage for Mississippi coast depth grids..... vii

Figure 3. SLOSH basins provide hurricane surge estimates for the entire coastline of the United States, including Hawaii. (Source: NOAA, weather.gov) viii

Figure 4. CONOPS Timeline. xii

Figure 5. Study area for SOP demonstration. 2

Figure 6. New Orleans SLOSH basin shapefile showing spatial coverage of all basin grid cells.. 3

Figure 7. Attribute table for category 1 MOM in the MS6 basin. 4

Figure 8. Biloxi/MS-Gulf Coast SLOSH basin with specifically attributed MOM category..... 4

Figure 9. Study area for the SOP. 5

Figure 10. MS6 basin overlaying the study area county. 5

Figure 11. This option in ET GeoWizards converts vector polygons to points. 6

Figure 12. Choose the polygon layer to convert to points as well as an output location and file name. 7

Figure 13.Select "centers" to extract the polygon centroids. 7

Figure 14. Point shapefile for the MS6 SLOSH basin. 7

Figure 15. Use the query builder to remove null values from the category MOM..... 8

Figure 16. Category 1 MOM null values are removed in this coverage. 9

Figure 17. Use the Select by Location tool to create select the points within a one-mile buffer around the study area. 10

Figure 18. MS6 basin points remaining after selection process using the one-mile buffer..... 11

Figure 19. Exporting data to dBASE table. 12

Figure 20. dBase file in Excel. 13

Figure 21. Formatting X and Y cells in Excel. 14

Figure 22. Make column C wide enough to accommodate the VERTCON elevation difference. It is highly recommended to make column C 215 pixels wide. 15

Figure 23. VERTCON startup screen. 16

Figure 24. VERTCON startup options. 16

Figure 25. Text file import wizard. 17

Figure 26. Text file import wizard Step 2. 18

Figure 27. Change the column headers accordingly. 18

DRAFT

Figure 28. Use the Add Data button to import the Excel file. 19
Figure 29. Join the elevation difference file to the SLOSH points layer. 20
Figure 30. Use the Field Calculator to convert from meters to feet. 21
Figure 31. Spatial resolutions and raster cell sizes. (Source: USGS, seamless.usgs.gov) 22
Figure 32. Settings for the IDW tool. 23
Figure 33. Flood surface generated from the IDW interpolation. 23
Figure 34. The Hazus Depth Grid Tool as seen from Model Builder. 24
Figure 35. Inputs necessary to run the Hazus Depth Grid Tool. 25
Figure 36. The Hazus Depth Grid Tool produces a raster which and be imported directly into Hazus 2.0 and used for refined analysis at level 2. 26
Figure 37. The vector polygon produced by the Depth Gird Tool is roughly the same file used for the HES. These vector polygons can be overlaid for numerous maps analyses and visual displays. The Category 1 SLOSH MOM points overlay the polygon. 26
Figure 38. Category 1-5 MOMs for Hancock County, MS generated from the Hazus Depth Grid Tool and the USGS NED 30-meter data. 27
Figure 39. Flood Hazard Type setting. 29
Figure 40. Hazus User Defined Depth Grid interface. 29
Figure 41. Set Parameters of depth grid to feet. 29
Figure 42. New Study Case Scenario wizard. 30
Figure 43. Use the scenario wizard to select your depth grid for analysis in Hazus. 31
Figure 44. After supplying a depth grid, you need to delineate the coastal floodplain. 32
Figure 45. Hazus Analysis options, processing status, and analysis time. 33
Figure 46. View Scenario by Results. 34
Figure 47. Hazus Summary Reports menu for Direct Economic Losses for Buildings (DELB) and Global Summary Report. 35
Figure 48. Export/Backup Region window. 36
Figure 49. Region export completed window. 36
Figure 50. VERTCON download page on the National Geodetic Survey website. 39
Figure 51. Potentially flooded facilities (Level-1 Hazus data) for Hurricane Dolly at NHC Advisory #10. 40
Figure 52. Potentially flooded facilities (Level-1 Hazus data) for Hurricane Dolly at NHC Advisory #13. 41
Figure 53. Maximum Sustained Winds of Hurricane Jerry Impacting Georgia. 63
Figure 54. Estimated Displaced Households for Hurricane Jerry in Georgia. 64

DRAFT

Figure 55. Estimated Displaced People Seeking Temporary Public Shelter for Hurricane Jerry in Georgia. 65
Figure 56. Estimated Potential Brick and Wood Debris for Hurricane Jerry in Georgia. 66
Figure 57. Estimated Potential Tree Debris for Hurricane Jerry in Georgia. 67
Figure 58. Potential Impacted Medical Care Facilities for Hurricane Jerry in Georgia. 68
Figure 59. At Least Moderate Damage to Residential Structures for Hurricane Jerry in Georgia. 69
Figure 60. Category 1-5 Storm Surge Inundation Boundaries for Coastal Georgia. 70
Figure 61. Category 1-5 Storm Surge Inundation Boundaries for Bryan County, Georgia. 71
Figure 62. Category 1-5 Storm Surge Inundation Boundaries for Camden County, Georgia. 72
Figure 63. Category 1-5 Storm Surge Inundation Boundaries for Chatham County, Georgia. 73
Figure 64. Category 1-5 Storm Surge Inundation Boundaries for Glynn County, Georgia. 74
Figure 65. Category 1-5 Storm Surge Inundation Boundaries for Liberty County, Georgia. 75
Figure 66. Category 1-5 Storm Surge Inundation Boundaries for McIntosh County, Georgia. 76
Figure 67. Potential Shelter Population for a Category 2 Storm Surge in Coastal Georgia. 77
Figure 68. Potential Shelter Population for a Category 3 Storm Surge in Coastal Georgia. 78
Figure 69. Building Loss Ratio for a Category 2 Storm Surge in Coastal Georgia. 79
Figure 70. Building Loss Ratio for a Category 3 Storm Surge in Coastal Georgia. 80
Figure 71. Estimated Debris Total for a Category 2 Storm Surge in Coastal Georgia. 81
Figure 72. Estimated Debris Total for a Category 3 Storm Surge in Coastal Georgia. 82

DRAFT