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Florida Coastal High Water Mark (CHWM) Collection
FEMA-1545-DR-FL

Final Report

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Table of Contents

INTRODUCTION 1

AREA OF STUDY 6

MARKING AND SURVEY METHODOLOGY 9

ELEVATION CONVERSION FROM NAVD88 TO NGVD29 USING VERTCON 12

FINDINGS AND OBSERVATIONS 13

RECOMMENDATIONS 15

Appendices

Appendix A: Figures

Appendix B: Survey Sheets from Volusia County

Appendix C: Survey Sheets from Brevard County

Appendix D: Survey Sheets from Indian River County

Appendix E: Survey Sheets from St. Lucie County

Appendix F: Survey Sheets from Martin County

Appendix G: Survey Sheets from Palm Beach County

Appendix H: Survey Sheets from Manatee County

Appendix I: Survey Sheets from Hillsborough County

Appendix J: Survey Sheets from Pinellas County

Appendix K: Survey Sheets from Levy County

Appendix L: Survey Sheets from Dixie County

Appendix M: Survey Sheets from Taylor County

List of Figures

Figure 1: Hurricane Frances Approaches 1

Figure 2: Hurricane Frances Storm Path 2

Figure 3: Disaster Declaration Map 4

Figure 4: Sample CHWM Flagger Form 9

Figure 5: Sample CHWM Surveyor Form 11

Figure 6: Hurricane Frances CHWM Surveyed Open Coast Elevations A-1

Figure 7: Hurricane Frances CHWM Surveyed Back-Shore Coast Elevations A-2

Figure 8: Volusia County Surveyed CHWM Elevations A-3

Figure 9: Brevard County Surveyed CHWM Elevations A-4

Figure 10: Indian River County Surveyed CHWM Elevations A-5

Figure 11: St. Lucie County Surveyed CHWM Elevations A-6

Figure 12: Martin County Surveyed CHWM Elevations A-7

Figure 13: North Palm Beach County Surveyed CHWM Elevations A-8

Figure 14: South Palm Beach County Surveyed CHWM Elevations A-9

Figure 15: Hurricane Frances CHWM Surveyed Tampa Bay Area Elevations A-10

Figure 16: Lower Big Bend Surveyed CHWM Elevations A-11

Figure 17: Upper Big Bend Surveyed CHWM Elevations A-12

List of Tables

Table 1: Number of CHWMs Surveyed by County 7

Table 2: NOAA NWS Gauge Stations During Hurricane Frances 7

Table 3: USGS Gauge Stations During Hurricane Frances 8

Introduction

Hurricane Frances was the second of four deadly hurricanes that ripped through the state of Florida during the 2004 season, just weeks after Hurricane Charley left its catastrophic mark. Frances first passed through the Bahamas on September 2, 2004, blowing devastating winds and placing sections of some islands completely underwater. Frances' eye moved only 5 to 10 miles per hour (mph) as it slowly made its way toward the shores of Florida.

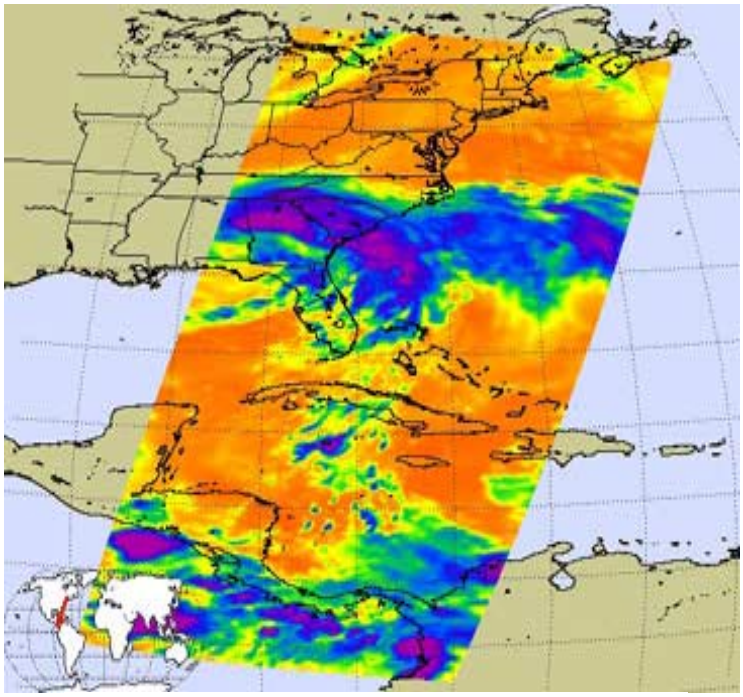

Figure 1. Hurricane Frances Approaches

Frances struck a wide stretch of Florida's east coast early Sunday, September 5, 2004, with winds of 105 mph, making it a Category 2 hurricane on the Saffir-Simpson scale. The storm dropped more than 13 inches of rain and knocked out power to millions of residents. Other main effects from this storm were damage to roofing materials, doors, windows, and piers, and considerable damage to mobile homes and vegetation. Hurricane Frances hit Florida with reported maximum sustained winds of over 105 mph with storm surges over 5 feet. Hurricane-force winds extended outward up to 75 miles from the center, and tropical storm-force winds extended outward up to 205 miles. The image of Hurricane Frances (Figure 1) was acquired by the Atmospheric Infrared Sounder (AIRS) infrared, microwave, and visible sensors on September 7 at 1:30 a.m. local time as the storm moved into Georgia (http://airs.jpl.nasa.gov/multimedia/image_releases/2004/hurricane_frances.html). Figure 1 shows how the storm looked through an AIRS Infrared window channel.

Frances made landfall near Sewall's Point, Florida, around 1:00 a.m., on Sunday, September 5, 2004, as a Category 2 storm, then moved west across the central Florida peninsula while weakening to a tropical storm. The tropical storm then re-emerged into the northeast Gulf of Mexico just north of Tampa, Florida, and made a second landfall at Saint Mark's, Florida, in the Florida Panhandle region (Figure 2). As the hurricane moved through Florida, wind and wave action disrupted utilities, caused damage, and created localized flooding.

Figure 2: Hurricane Frances Storm Path

The State of Florida Department of Environmental Protection issued an Emergency Final Order stating that the hurricane caused widespread damage in the following counties: Alachua, Brevard, Broward, Citrus, Glades, Hardee, Hernando, Highlands, Hillsborough, Indian River, Lake, Manatee, Marion, Martin, Okeechobee, Orange, Osceola, Palm Beach, Pasco, Pinellas, Polk, St. Lucie, Seminole, and Volusia.

The storm continued to move north-northeast. The tropical storm weakened to a depression near Albany, Georgia, then moved slowly north across central and northeast Georgia, the mountains of extreme western North Carolina, and southwest Virginia, West Virginia, western Pennsylvania, and New York.

Other notable wind data were measured by the Florida Coastal Monitoring Project (FCMP) and made available through PRNewswire-FirstCall. For the first time, homes instrumented as part of the FCMP captured wind pressure data on buildings subjected to the direct impact of hurricane-force winds. The highest 3-second gust winds measured in Hurricane Frances were 106 mph at an open-exposure site south of Fort Pierce.

Notice was given in the *Federal Register*, in a letter dated September 4, 2004, that the President declared a major disaster under the authority of the Robert T. Stafford Disaster Relief and Emergency Assistance Act for damage in certain areas in Florida resulting from Hurricane Frances (FEMA-1545-DR-FL; http://www.fema.gov/news/dfrn.fema?id=2902). The declaration provides the necessary federal assistance to meet immediate needs and to help Florida recover as quickly as possible. Florida counties under disaster declaration FEMA-1545-DR-FL are shown on Figure 3.

Individual Assistance was provided to*:* Brevard, Indian River, Martin, Palm Beach, and St. Lucie Counties with the September 4, 2004, declaration. Broward, Citrus, Glades, Hernando, Highlands, Lake, Miami-Dade, Okeechobee, Orange, Osceola, Pasco, Polk, and Sumter Counties were included with Amendment No. 1 to the Notice of a Major Disaster Declaration, September 5, 2004.

Amendment No. 2, September 7, 2004, included Alachua, Clay, Duval, Flagler, Hendry, Putnam, Seminole, St. Johns, and Volusia Counties for Individual Assistance.

Amendment No. 3, September 9, 2004, included Charlotte, Columbia, DeSoto, Dixie, Gilchrist, Hardee, Hillsborough, Levy, and Marion Counties for Individual Assistance.

Amendment No. 4, September 10, 2004, included Baker, Bradford, Lee, Nassau, Pinellas, and Union Counties for Individual Assistance.

Amendment No. 8, September 25, 2004, included Manatee, Sarasota, and Suwannee Counties for Individual Assistance.

Public Assistance was provided to all counties within the State of Florida for assistance for debris removal and emergency protective measures, including direct federal assistance, at 100 percent federal funding of the total eligible costs of Categories A and B for a period of up to 72 hours. Consistent with the requirement that federal assistance be supplemental, any federal funds provided under the Stafford Act for Public Assistance will be limited to 75 percent of the total eligible costs.

Amendment No. 5 to the Notice of a Major Disaster Declaration, September 15, 2004, included Broward, Calhoun, Citrus, Columbia, DeSoto, Duval, Flagler, Hardee, Highlands, Hillsborough, Indian River, Jefferson, Lake, Levy, Manatee, Martin, Okeechobee, Orange, Osceola, Palm Beach, Polk, Sarasota, Seminole, St. Johns, Suwannee, and Volusia Counties for Public Assistance Categories C-G under the Public Assistance program.

Amendment No. 6, September 21, 2004, included Baker, Bradford, Dixie, Hernando, Liberty, Marion, and St. Lucie Counties for Categories C-G under the Public Assistance program.

Amendment No. 7, September 23, 2004, included Alachua, Brevard, Clay, Gilchrist, Nassau, Pasco, Putnam, and Sumter Counties for Categories C-G under the Public Assistance program.

Amendment No. 9, September 27, 2004, included Gadsden, Glades, Hamilton, Hendry, Leon, Madison, Union, and Wakulla Counties for Categories C-G under the Public Assistance program.

Amendment No. 12, November 3, 2004, included Franklin County for Public Assistance Categories C-G under the Public Assistance program.

Amendment No. 13, December 3, 2004, included Lafayette and Taylor Counties for Public Assistance Categories C-G under the Public Assistance program.

Figure 3: Disaster Declaration Map – Florida

Source: http://www.gismaps.fema.gov/2004graphics/dr1545/dec_1545.pdf

Hazard Mitigation Grant Program (HMGP): All counties in the State of Florida are eligible to apply for assistance under the HMGP.

URS Group, Inc., (URS) was contracted by the Federal Emergency Management Agency (FEMA) under the Hazard Mitigation Technical Assistance Program (HMTAP) to assist in the Hurricane Frances disaster recovery. Assistance provided by this Task Order includes collection and survey of Coastal High Water Marks (CHWMs). This report summarizes the methodologies used to flag the CHWM locations and survey the elevations established during the hurricane. This is an important step in assisting communities to establish flood hazard areas and to prevent future loss of life and property damage.

Hurricane Frances caused both coastal and riverine flooding. The resulting high water marks were flagged and surveyed along coastal locations. The purpose of this report is to document the flagging and surveying of the CHWMs, estimate the storm surge at each location, and discriminate between storm surge and wave action.

The data collected are invaluable to federal, state, and local recovery efforts. The data assist in identifying areas of significant damage in order to target resources needed for disaster recovery. They also help to establish the magnitude and recurrence interval of the flood and erosion events caused by the hurricane along various areas of the coast. This data collection is also beneficial for future use in (a) accurately assessing the benefits to be expected from flood mitigation efforts, (b) prioritizing the flood mitigation efforts pursued following the hurricane, and (c) making HMGP decisions.

Area of Study

The area identified by FEMA to be covered by the Coastal High Water Study Team extended on the east coast of Florida from Volusia County southward to Palm Beach County and on the west coast from Manatee County northward into the Florida Panhandle to Wakulla County. Along the east coast, the observations were taken at discrete points distributed along the open Atlantic coast, on the seaward and landward sides of the barrier islands, and on the shores of several small embayments including the North and South Fork and Indian rivers. A 20-mile section of the open coast was not accessible for flagging CHWMs due to the presence of a high dune running parallel to the coast extending from the St. Lucie/Martin County line southward to Jupiter Inlet. In this area the surge did not exceed the dune height, and those structures that were still standing were too unsafe to flag. CHWM points were not taken at Cape Canaveral because this area was off limits to flagging crews. Along the Gulf Coast, observations were taken at discrete points distributed along the shorelines of Old Tampa Bay and Hillsborough Bay, small embayments, and the open coast.

URS was authorized to initiate the CHWM project on Thursday, September 9. Prior to dispatching the field parties, a work plan was developed and submitted to FEMA on September 10. This plan was based on results from the National Oceanic and Atmospheric Administration (NOAA) Sea, Lake and Overland Surges from Hurricanes (SLOSH) Model and a review of data from the tide gauges along both coasts. Based on this information, URS established the limits of the east coast area to be between New Smyrna Beach (just north of Cape Kennedy) on the north and West Palm Beach on the south. On the west coast, URS planned to cover the area from the Manatee River (estuary) on the south to Cedar Key on the north. Most of the west coast effort would be focused in the upper portions of Tampa and Hillsboro Bays and some of the small coastal estuaries.

The NOAA SLOSH model also predicted surge heights up to 4.3 feet in southern Collier and Monroe Counties (South of Marco Island). Similar surge predictions (up to 7.2 feet) have been made by NOAA for Apalachee Bay (Wakulla and Taylor Counties) near Tallahassee. In consultation with Shabbar Saifee and Alan Springett of the FEMA Disaster Field Office, it was decided that the Marco Island and Tallahassee areas were too removed from the other field areas. Because Hurricane Ivan was forecasted to impact some of the same areas affected by Frances within 3 days, no measurements were planned for these four counties outside of the main impact regions.

Based on the general patterns of the storm surge on the open coasts and within the bays and lagoons, 42 sub-regions were selected to be visited by the field parties. Each area was searched for valid CHWMs. Where possible, more than one mark was located in each sub-area. However, some portions of the barrier islands were not accessible, and others showed no valid CHWMs. On the other hand, field parties made on-site decisions that added more CHWMs. Additionally, Hurricane Jeanne took several days longer to make landfall than originally expected, providing more time to collect additional CHWMs. It was decided to have a Tallahassee-based flagger visit Cedar Key. This presented the opportunity to survey five additional CHWMs along the shore of Apalachee Bay where the NOAA SLOSH model had predicted the surge to be less than 7 feet. In

this area, also known as the Big Bend of Florida, access to the coast is very limited due to the vast expanse of salt marsh and wetlands. The CHWM locations along this part of the coast were selected on the basis of accessibility and their usefulness as aids in determining the northern limit of the storm surge.

Sixty-two CHWMs were surveyed in 12 counties. These are listed by county in Table 1.

Table 1: Number of CHWMs Surveyed by County

County	Number of CHWMs Surveyed
Volusia	3
Brevard	6
Indian River	11
St. Lucie	4
Martin	9
Palm Beach	7
Manatee	5
Hillsborough	9
Pinellas	3
Levy	2
Dixie	2
Taylor	1
Total =	62

The NOAA tide gauges that were operating in the area during the time of the hurricane and their peak elevation during the hurricane are shown on Table 2.

Table 2: NOAA NWS Gauge Stations During Hurricane Frances

Station ID	Name	Latitude (North)	Longitude (West)	Hurricane Frances Peak Elevation (Ft) MLLW
8721604	Trident Pier, FL	28° 24.9' N	80° 35.6' W	6.8 ft
8723214	Virginia Key, FL	25° 43.9' N	80° 09.7' W	2.9 ft
8726384	Port Manatee, FL	27° 38.2' N	82° 33.8' W	4.5 ft
8726520	St. Petersburg, FL	27° 45.6' N	82° 37.6' W	5.0 ft
8726724	Clearwater Beach, FL	27° 58.6' N	82° 49.9' W	4.3 ft
8727520	Cedar Key, FL	29° 08.1' N	83° 01.9' W	6.5 ft

MLLW = mean lower low water.

The U.S. Geological Survey (USGS) gauges in operation along the east and west coast during Hurricane Frances are shown in Table 3. The data for these gauges were collected from the Miami, Tampa, and Orlando USGS offices.

Table 3: USGS Gauge Stations During Hurricane Frances

Station ID	Name	Latitude (North)	Longitude (West)	Hurricane Frances Peak Elevation (Ft) NGVD
2310207	ANCLOTE RIVER AT HICKORY PT AT ANCLOTE, FL	28.17139	82.78500	2.9 ft
2310600	GULF OF MEXICO NEAR BAYPORT, FL	28.53333	82.65028	3.9 ft
2301721	ALAFIA RIVER AT GIBSONTON, FL	27.85944	82.38444	5.7 ft
2300554	LITTLE MANATEE RIVER AT SHELL POINT NEAR RUSKIN, FL	27.71806	82.48194	4.7 ft
2310700	HOMOSASSA RIVER AT HOMOSASSA, FL	28.78500	82.61806	2.3 ft
2310650	CHASSAHOWITZKA RIVER NEAR HOMOSASSA, FL	28.71500	82.57722	4.1 ft
2306028	HILLSBOROUGH RIVER AT PLATT STREET AT TAMPA, FL	27.94167	82.45889	5.8 ft
265645080 055900	LOXAHATCHEE RIVER AT POMPANO DR. NEAR JUPITER, FL	26.94583	80.09972	4.5 ft
262358080 055700	E-4 CA AT CLINT-MOORE RD IN BOCA RATON, FL	26.39944	80.09917	5.7 ft
265651080 045500	LOX RIVER AT COAST GUARD DOCK NEAR JUPITER, FL	26.94750	80.08194	4.5 ft
02279000 (upstream)	WEST PALM BEACH CANAL AT WEST PALM BEACH, FL	26.64444	80.05889	8.8 ft
02247509	ELEVENTH STREET CANAL AT HOLLY HILL, FL	29.24556	81.04167	5.3 ft
02247509	ELEVENTH STREET CANAL AT HOLLY HILL, FL	29.24556	81.04167	5.3 ft
02251767	FELLSMERE CANAL NEAR MICCO, FL	27.83028	80.53444	5.6 ft
02248380	HAULOVER CANAL NEAR MIMS, FL	28.73639	80.75472	1.6 ft
02249518	CRANE CREEK AT U.S. HIGHWAY 1 AT MELBOURNE, FL	28.07694	80.60250	4.4 ft
02251800	INDIAN RIVER AT WABASSO, FL.	27.75417	80.42778	4.7 ft

NGVD = National Geodetic Vertical Datum of 1929.

Marking and Survey Methodology

Field and survey crews from URS and URS Team sub-consultants, Dewberry and PBS&J, were deployed to conduct resident interviews, find evidence of coastal high water levels, take digital photographs, and survey CHWMs from Hurricane Frances. Figures 4 and 5 show an example of the flagger form and surveyor form used to record field information. During the flagging, field crews entered estimates of surge heights in the Comments field. These were visual estimates and were referenced to the normal range of the tides as best estimated by the observers. The purpose of these observations was to get an initial estimate well before the surveyors' work would be completed. The CHWM flagging crews were deployed on Monday, September 10, 2004, shortly followed by the survey crews.

Figure 4: Sample CHWM Flagger Form

HIGH WATER MARK (HWM) REPORT – FLAGGERS

HWM ID	
Stream Name	
Unit Number	
Name of Crew / Interviewer	
Company	
Date of flagging / Interview	
Date of flood event	
Name of storm event	
Address of HWM	
Location / Description of Mark	
Vertical distance from set point & description of set point	
HWM Object	

Type of Mark	
Type of HWM	
HWM Quality	
Flood Type	
City	
County	
State	
Witness Information:	Name: Address: Telephone Number How long lived there: Obtained permission to survey?
HWM ID (from first page)	
Photo ID	
Photo Location/ Orientation	
Photo Description/ Subject	
Flagger HWM Latitude	
Flagger HWM Longitude	
Comments	
Was wind damage in the area observed? If so, describe (Note: For Internal Use Only)	

Figure 5: Sample CHWM Surveyor Form

HWM ID	
ADDRESS OF HWM	
Survey Date	
Surveyors	
Company	
Survey Accuracy (1)	
Projection	
Vertical Datum	NAVD 88
Horizontal Datum	NAD 83
Easting	
Northing	
HWM Elevation (2)	
First Floor Elevation (based on measurement from HWM)	

Global Positioning System (GPS) survey crews followed the field crews and used static GPS methods to determine an accurate elevation for each CHWM. Since static GPS requires an area with no tree cover to return an accurate result, in some cases it was necessary to perform a short level loop survey from the GPS point to the CHWM. Wherever possible, the finished floor elevation of structures adjacent to the CHWM was collected. This information may be used at a later date for possible damage assessments or HMGP applications. CHWM locations were surveyed horizontally in North American Datum of 1983 (NAD 83), State Plane feet, and vertically in North American Vertical Datum of 1988 (NAVD 88) US survey feet. CHWM locations have been surveyed to within accuracies of 0.25 foot vertically and 10 feet horizontally with a 95 percent confidence level.

Field crews noted CHWM characteristics such as surge, wave run-up, and wave height. These designations on the survey sheets in the appendices represent the flaggers' estimates of these characteristics based on a combination of physical flood evidence and interviews with witnesses at the time of collection. "Surge" represents the rise in the normal water level; "wave run-up" indicates the height of water rise above the still-water level due to water rush-up from a breaking wave; and "wave height" indicates CHWM elevation due to more direct wave action. Typically, surge CHWMs are associated with a slow-rising flood that causes more water damage than structural damage. Wave height usually corresponds to a higher flood elevation. All attempts were made to flag storm surge elevations, but in areas where surge characteristics were not obvious, wave run-up or wave height were flagged.

Elevation Conversion from NAVD88 to NGVD29 Using VERTCON

The elevations shown in the 1929 NGVD were derived from the VERTCON program and the existing 1988 (NAVD) elevation. The VERTCON software was developed by the National Geodetic Survey (NGS) Office to allow the conversion of data between different vertical data scales. VERTCON is available as an element of the NGS Geodetic Toolkit and can be downloaded at the NGS website: *http://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html*.

VERTCON allows the user to compute the modeled difference in orthometric height for a given location specified by its latitude and longitude. Applying the VERTCON datum difference value to a specific elevation allows the user to convert from one datum to another.

For example, the NAVD 88 elevation is 5.33 feet at UNIT 1-3. Using the latitude and longitude, VERTCON computes a datum shift of (-) 1.171 feet; to convert to the NGVD 29, SUBTRACT the datum shift from the NAVD 88 height. NAVD EL=5.33’ minus (-) 1.171 feet equals NGVD elevation of 6.501 feet.

Findings and Observations

The results of this survey are presented as a series of 12 maps shown on Figures 6-17 (Appendix A). The individual points are coded to differentiate between surge data (taken in places protected from the effects of waves) and wave run-up data (where the water line resulted from waves rushing up a slope). The relative quality of each data point is also represented. Further information about each point is given on data sheets in Appendices B-G.

The NOAA SLOSH model predicted the hurricane storm surge along the Atlantic coast of Florida to be greater along the open coast than along the shores of the bays and lagoons behind the barrier islands. In a relative sense, the surveyed CHWM elevations found this to be true. That is, although the measured and predicted heights differed, the patterns of higher and lower surge elevations were similar. To present the surge information so that the overall patterns are apparent, the open coast and backshore measurements are presented on Figures 6 and 7, respectively. The highest open coast surge-plus-wave setup elevation recorded during this study was in the area of Hobe Sound, approximately 9 miles south of where Frances made landfall at Stuart (Figure 6). The highest open CHWM elevations were recorded in the areas of Vero Beach and Jupiter. These elevations were the result of wave run-up.

Figures 6 and 7 show the CHWM values decreased slowly northward to 6.3 feet on Edgewater Beach, only to increase to 10.8 feet at New Smyrna Beach, the northernmost point. The inconsistent elevation of this point (unit1_5) is attributed to waves impacting on a seawall and cascading onto the ground behind the wall. Over 8 vertical feet of beach were lost during the storm. Because of the effects of wave slamming and cascading, this is not considered a valid point to be compared with the others from this storm. Several CHWMs south of the storm center show an increase in elevation going away from the point of landfall; however, these are from the combined effects of wave run-up and spilling wave heights. They are not indicative of a pure storm surge elevation. The points that are actual surge elevations show water levels decreasing away from the point of landfall.

Figures 8 through 14 show CHWMs and elevations by county. As mentioned above, elevations were significantly lower along the shores of back bays and lagoons. Figure 11 shows the exception. At the head end the North Fork of the St. Lucie River, elevations of 12.9 and 13.6 feet were recorded. This is the result of surge amplification towards the head of the bay.

The NOAA SLOSH model is used to make both near-real time predictions and better-supported post-storm simulations. For a run made in near-real time, the predicted surge levels were greatest in the upper reaches of the bays and estuaries along the central west coast of Florida. The model also predicted that the surge would be minimal along the beaches of the open Gulf of Mexico.

The surveyed elevations generally supported these predictions. However, there were significant differences between the surveyed maximum surge levels and the predicted values.

Figure 15 shows the CHWM levels along the central Florida Gulf coast. The highest levels were in the upper reaches of Tampa and Hillsboro Bays. In several places along upper Old Tampa Bay, Hillsborough Bay, and the upper reaches of small estuaries, the surge was amplified enough to cause minor flooding in residential neighborhoods.

Figures 16 and 17 show CHWM elevations along the Big Bend coast between Pasco County on the south to Taylor County on the north. There is a broad general trend to the CHWM levels across this portion of the coast.

Figures 8-10, and 13-16 show the locations and elevations recorded at gauges operated by NOAA and USGS. These are the gauges that were in operation during Hurricane Frances. These recorded elevations show the same overall measured patterns that are shown by the CHWMs. Surge levels were greater along the open coast than along the shores of the bays and lagoons behind the barrier islands.

Recommendations

The following recommendations discuss how FEMA can utilize the CHWM information to assist in the recovery effort from Hurricane Frances:

- Compare the Frances CHWMs to the flood elevation data on the effective or preliminary Flood Insurance Rate Maps. These comparisons can help FEMA determine where the updated flood hazard data were supported by the flooding that occurred or where new detailed studies should be performed to update the maps, and can help illustrate deficiencies on the existing maps.

- Compare the Frances CHWMs to HWMs from other significant flood events. This will identify areas of repetitive flooding that can assist FEMA in determining locations that would make good flood mitigation projects.

- Complete detailed engineering analyses to determine flood elevations in the areas where deficiencies have been identified on the existing FEMA maps, or in areas where property loss occurred where no previous studies have been prepared.

- Use the locations and severity of the Frances CHWMs to help FEMA identify areas of concern for future mitigation projects when funding for such projects becomes available.

- Use these CHWMs to evaluate the success of completed mitigation projects. The flood depths that occurred during Frances can be used to estimate potential damage that could have occurred to structures that have been bought out and removed as part of mitigation projects already completed. Documentation of the “damages avoided” can be used as success stories to further support the mitigation efforts.

- Create inundation maps for Hurricane Frances. The inundation maps would provide a plan view of the extent of flooding from Hurricane Frances and can assist in determining the accuracy of existing FEMA flood maps. The inundation mapping would be a spatially correct GIS coverage that could be provided to community officials to assist in disaster recovery.

- Provide this report on the Internet to aid public officials and the community in general in the recovery effort.