

**Appeal Submittal:
City of Key West, FL
Appeal of FEMA's Preliminary Flood Insurance Rate Maps
and Flood Insurance Study
(issued 12/27/2019)**

May 2021

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1.0 INTRODUCTION

On December 27, 2019, FEMA issued Preliminary Flood Insurance Rate Maps (FIRMs) and a Flood Insurance Study (FIS) report for the City of Key West, FL. The Woods Hole Group is supporting the City in its review of the FEMA-issued FIRMs and FIS.

The FEMA-proposed flood hazard determinations are subject to a 90-day statutory appeal period during which the community and/or individual property owners can submit an appeal by presenting scientific or technical data that indicate FEMA's proposed flood hazard determinations are incorrect. The 90-day appeal period for the City of Key West (the City) commenced on March 19, 2021, and ends on June 17, 2021.

Since 2018 the City has been engaged with FEMA during the process of developing these preliminary maps (see Appendix E for a list of prior correspondence between the City and FEMA [file: KeyWest-List_of_Data_Requests.xlsx]). After FEMA issued the preliminary maps, the City sent correspondence to FEMA on February 5, 2020, with an itemized list of concerns/questions. FEMA responded to the City on June 11, 2020, and the City sent a follow-up itemized list of concerns/questions on July 7, 2020. FEMA again responded to the City on August 18, 2020; however, they did not address the concerns through any reanalysis. Appendix E contains the correspondence between FEMA, the City, and Monroe County after issuance of the preliminary maps. This left the burden of reanalysis on the City to further investigate these concerns and the correctness of FEMA's study.

Woods Hole Group completed a reanalysis of FEMA's December 2019 RiskMap study for the City with Ransom Consulting working as a subconsultant. This reanalysis determined that FEMA's proposed flood hazard determinations are incorrect.

This document and supporting technical information constitute the City's appeal of the Preliminary FIRMs and FIS.

2.0 SCOPE OF APPEAL

The scope of this appeal is the entirety of the City of Key West including the FIRM panels shown in Figure 1 and listed in Table 1 below.

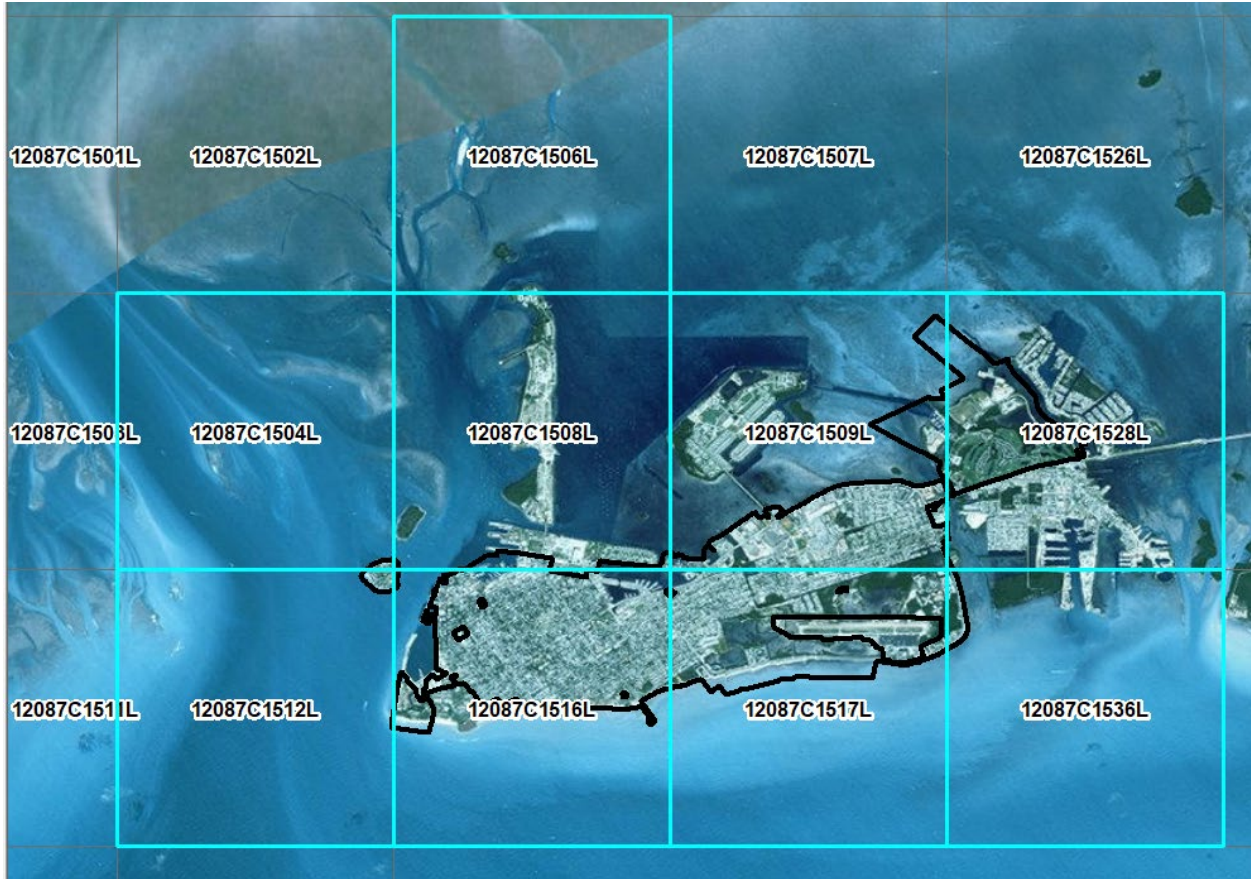


Figure 1. The City of Key West FEMA FIRM panels that are included in the scope of this appeal (outlined in white)

Table 1. List of FEMA FIRM panels included in the City of Key West appeal

	12087C1506L		
12087C1504L	12087C1508L	12087C1509L	12087C1528L
12087C1512L	12087C1516L	12087C1517L	12087C1536L

3.0 BASIS FOR APPEAL

The City’s appeal is submitted on the basis that FEMA’s preliminary BFEs, SFHA zone designations, and the extent of the SFHA are both technically and scientifically incorrect. FEMA did not appropriately characterize flood hazards in the City due to the technical approach and assumptions that were applied and because FEMA attempted to include the Florida Keys in its regional study that was better suited for the populated mainland Florida Counties (Miami-Dade, Broward, and Palm Beach).

While Monroe County has a mainland presence (87% of the area of Monroe County), the mainland geography is largely unpopulated and undeveloped with a 2010 census population of 9 and a comparably small percentage of developed property (Current property tax rolls show 8 residential parcels with a total market value of approximately \$327,000 and 2 vacant residential parcels.) Monroe County’s areas of consequence to FEMA for support of the National Flood Insurance Program, and the protection of



property and lives from flood hazards lies almost exclusively within the island chain generally identified as the Florida Keys.

The City has conducted a reanalysis of certain aspects of FEMA’s study in support of this appeal that is more applicable for the Florida Keys considering its population and property distribution, geography (over 100 miles of shoreline extending from the mainland), its unique characteristics (chain of islands interconnected by myriad of channels with extensive nearshore reefs) and makes use of better and more recent data such as Hurricane Irma.

FEMA’s preliminary FIRM maps are technically incorrect because a methodology was used with insufficient data, and the City possess higher quality data that are more correct than the data used by FEMA. FEMA’s preliminary FIRM maps are scientifically incorrect because 1) a methodology was used that was inappropriate and, 2) some of the assumptions made as part of the methodologies used are inappropriate or incorrect.

To demonstrate that insufficient or poor-quality coastal analysis data were used, this appeal submittal includes:

- Data believed to be better than those used in the original coastal analysis.
- Documentation for the source of the new data.
- An explanation of the improvement resulting from use of the new data.
- New coastal analysis based on the better data and updated stillwater elevation values.
- Revised SFHA boundary delineations and all applicable FIS report tables, including the transect data table, which demonstrate the use of more correct data would result in a change in SFHA determination.

To demonstrate that an inappropriate methodology or assumptions were used, this appeal submittal includes:

- New hydrologic analysis based on an alternative methodology and updated coastal analyses based on the updated stillwater elevation values.
- An explanation for the superiority of an alternative methodology.
- Revised wave envelope profiles, Transect Data Table, and Summary of Stillwater Elevations Table.
- Revised SFHA zone boundaries, which demonstrate the use of more correct methodologies and assumptions would result in a change in the SFHA determination.

4.0 AREAS OF SCIENTIFIC AND/OR TECHNICAL DEFICIENCY/IMPROVEMENT

This section lists the primary areas of concern identified in FEMA’s RiskMap study:

- 1) Storm Climatology and Selection for Florida Keys,
- 2) Statistical Analysis of Storm Sets, Low-Frequency Water Levels and Waves,
- 3) Wave Model Validation,
- 4) Hydrodynamic/Wave Model Mesh Resolution, and
- 5) Hydrodynamic/Wave Model Parameterization of Reefs.



These areas of concern were identified because of (a) the use of a non-standard approach, (b) inconsistencies in methodology with other FEMA Coastal RiskMap studies, (c) discrepancies between the study’s documentation and the analyses, or (d) errors made in the analysis.

For each issue, a description is given of why FEMA’s approach and/or analysis is technically or scientifically incorrect, and an explanation is given describing how the issue is addressed through the use of more correct alternative methodologies and data.

4.1 STORM CLIMATOLOGY & SELECTION FOR FLORIDA KEYS

Description of Issue(s)

FEMA used a single Coastal Reference Point (CRP) in Miami-Dade County for characterizing the historical storm climatology to establish a set of synthetic storms for modeling. This resulted in a storm characterization that is not representative of the local storm climatology in the Florida Keys. The storms defined using this single CRP are not representative of the observed storm rate and intensity in the Florida Keys. The adjacent Southwest Florida RiskMap study used spatially varied storm rates and storm parameters; this type of analysis is more appropriate for the Keys with its shoreline extending over 100 miles from the mainland. It was also found that many of the synthetic production storms (derived from historical storms with no land mass interaction) were tracked across Caribbean land masses and did not include attenuation caused by those land masses.

The CRP used by FEMA is shown in Figure 2 along with extrapolated offshore tracks for historical storms based on the landfall track heading or heading at the point of closest approach. Also shown in this figure is the 200 km radius from the CRP which is used in the calculations to define storm rates. This figure also denotes the City of Key West which is located outside of this 200 km radius. This clearly indicates FEMA’s calculated storm rates (dependent on distance from the CRP) are more appropriate for Miami-Dade, Broward, and Palm Beach counties. If FEMA used a CRP at a more central location for the Florida Keys (i.e., City of Marathon), the analysis of storm rates would certainly produce different results which would be more applicable for Key West.

In FEMA’s Intermediate Data Submittal (IDS) Report 1 Section 5, there is discussion of a sensitivity analysis FEMA conducted using multiple CRPs. This analysis showed the use of multiple, spatially distributed CRPs produced lower storm rates, however FEMA decided to use only the one CRP stating that “*one CRP results in a slightly higher rate and is a more conservative choice*”. Figure 3 (FEMA’s Figure 5.4 from IDS 1 Section 5 with annotations) shows the results of FEMA’s analysis and the sensitivity of storm rate to the number of CRPs. This illustrates that the difference in storm rate between 1 and 3 CRPs is not insignificant. For example, with 3 CRPs the storm rate is reduced by greater than 15% for storms with a heading of -50 degrees. This indicates that a more robust approach would result in more correct evaluation of the storm characterization.

This difference in storm rates related to the number of CRPs was also called out by comments from FEMA’s Technical Steering Committee, which notes the use of one CRP may be cleaner for the analysis (comments relevant to this appeal are extracted and provided in Appendix D).

Reviewer’s comment:



“I agree with the choice of 1 CRP per shoreline, but in both cases the choice of a single point results in a slightly increased storm rate, as compared to choosing 2 or 3 CRPs. Is it fair to say that in addition to being cleaner for the analysis, the choice of 1 CRP on each shoreline is slightly conservative?”

While it may be more straightforward with one CRP, it can be seen how the use of more CRPs or a spatially varied approach would be more scientifically correct. Additionally, in FEMA’s evaluation of storm rate sensitivity to number of CRPs, the CRPs used were all located in close proximity to the Florida mainland and did not extend into the Keys, as shown in Figure 4.

Figure 4 shows 6 CRPs, 3 of which were used for storms approaching the east coast and 3 for storms approaching the west coast. It can be seen how the 3 east coast CRPs did not provide a representative assessment for the Florida Keys (all are located north of the mainland’s southern tip). If FEMA added a CRP in the Keys there would be a different result, showing more sensitivity on the storm rate based on the number of CRPs and the differences that exist in the historical storm climatology. Additionally, the 3 west coast CRPs shown in Figure 4 are located in Monroe County, however they are located in the unpopulated Florida Everglades and do not extend into the Keys.

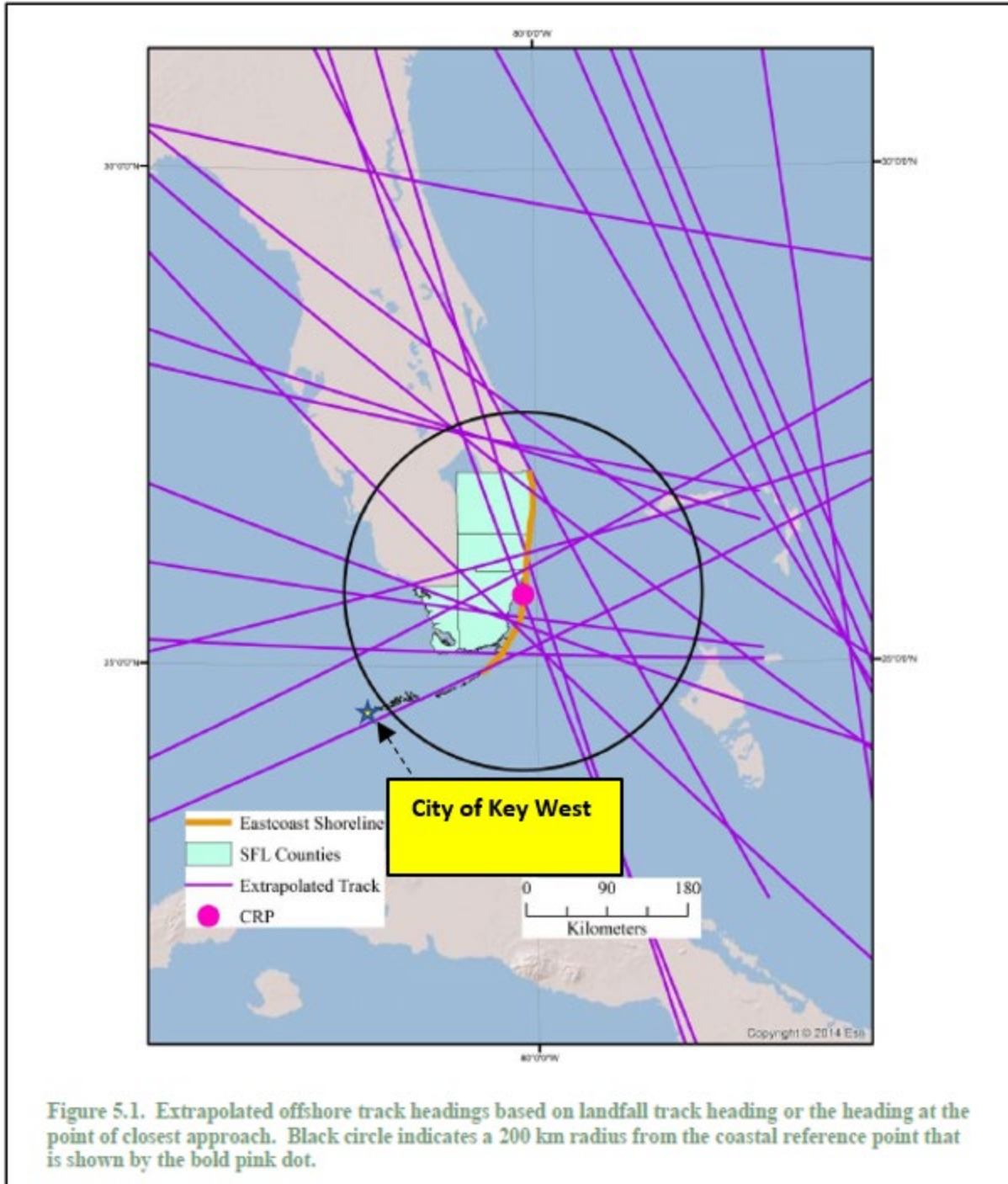


Figure 2. FEMA Figure 5.1 from IDS 1 Section 5 (annotated to show Key West)

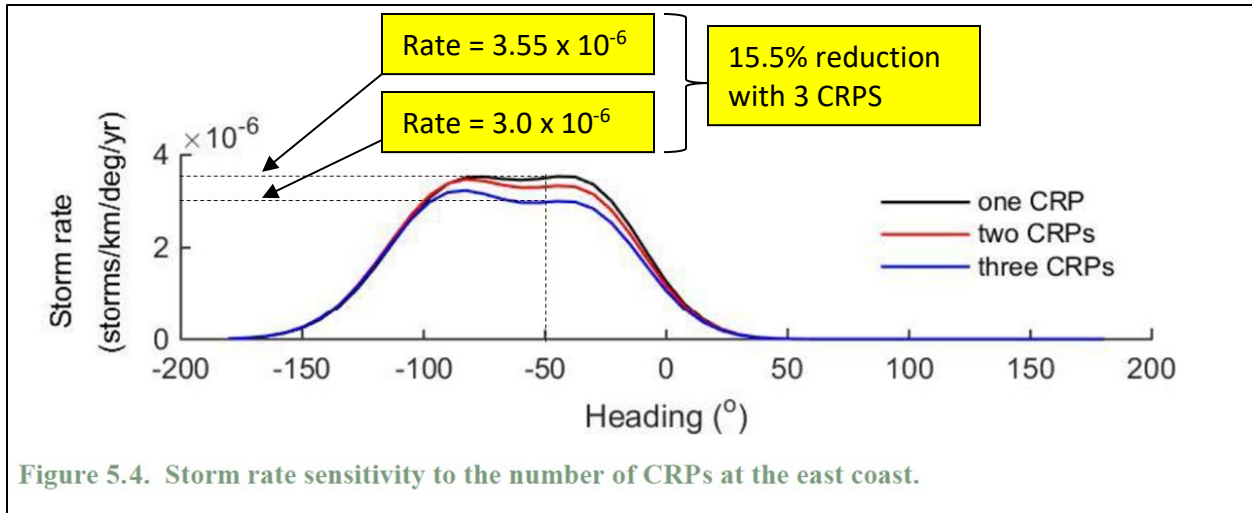
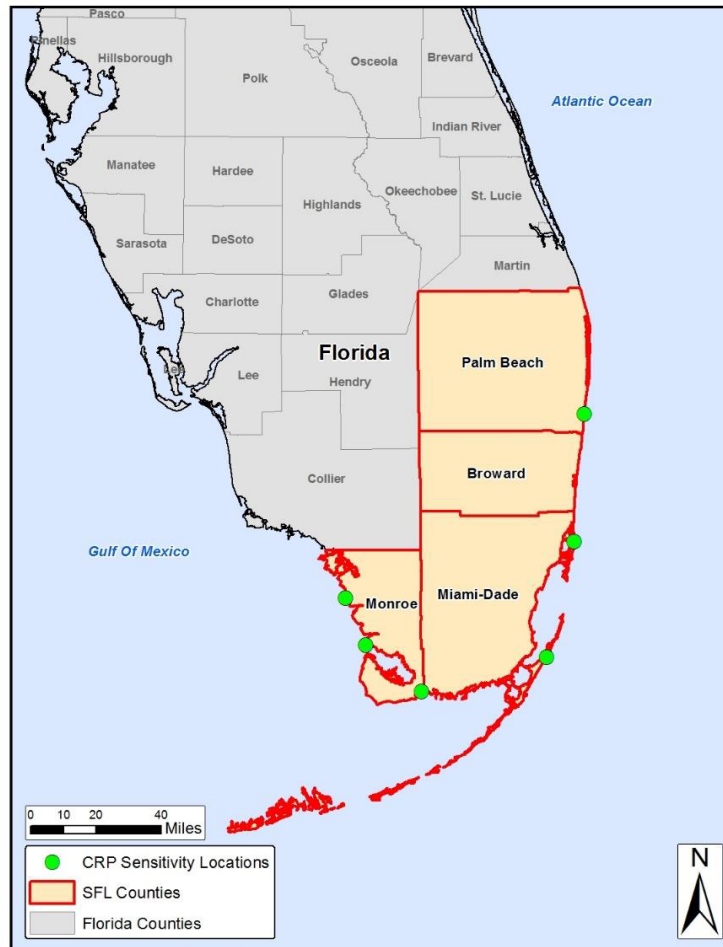


Figure 3. FEMA Figure 5.4 from IDS 1 Section 5 (annotated to show difference in storm rate at heading = -50 deg)





Another issue found in the City’s review relates to the synthetic storm development and treatment of storms that tracked over land masses.

From FEMA IDS Report 1, Section 5 JPM-OS Probabilistic Model Development (see page 7):

“For the purposes of the probabilistic model, the Florida Keys are not treated explicitly. The storm population impacting the Keys is a combination of the storms impacting both the west and east coasts of SFL; therefore, the storm population impact on the Keys is implicitly treated within the development of the other two probabilistic storm sets. IDS2-Section2 will deal with the development of the optimized storm set, and the treatment of the Florida Keys will be handled through replication of storm tracks across the Florida Keys.”

This implicit treatment of the Keys points to the single CRP issue previously discussed and the replication of storm tracks introduced another concern. FEMA characterized the historical storm climatology using a CRP on the Florida mainland. Many of the historical storms impacting the mainland did not have any significant interaction with land masses (i.e., Hurricane Andrew). FEMA then used the historical storm climatology for the development of the production synthetic storms. This led to the development of synthetic storms appropriate for the mainland and these storm tracks were then replicated south down through the Florida Keys. The synthetic storm tracks replicated across the Keys then crossed over significant land masses where typically there is attenuation of the storm’s intensity (based on recorded historical storms such as David (1979), Georges (1998), and Irma (2017)).

Figure 5 shows a sample of FEMA’s replicated synthetic storm tracks and a review of these synthetic storms showed there was no attenuation (or decrease in storm intensity) due to the interaction with Cuba and other land masses. Out of the 392 synthetic production storms, 72 storms pass over the long axis of Cuba (33 making landfall on the east coast and 39 making landfall on the west coast).

The combination of developing storms better suited for the mainland, replicating those storms across the Keys, and then not including storm attenuation due to interactions with land masses led to a scientifically incorrect characterization of flood hazard in the Keys.

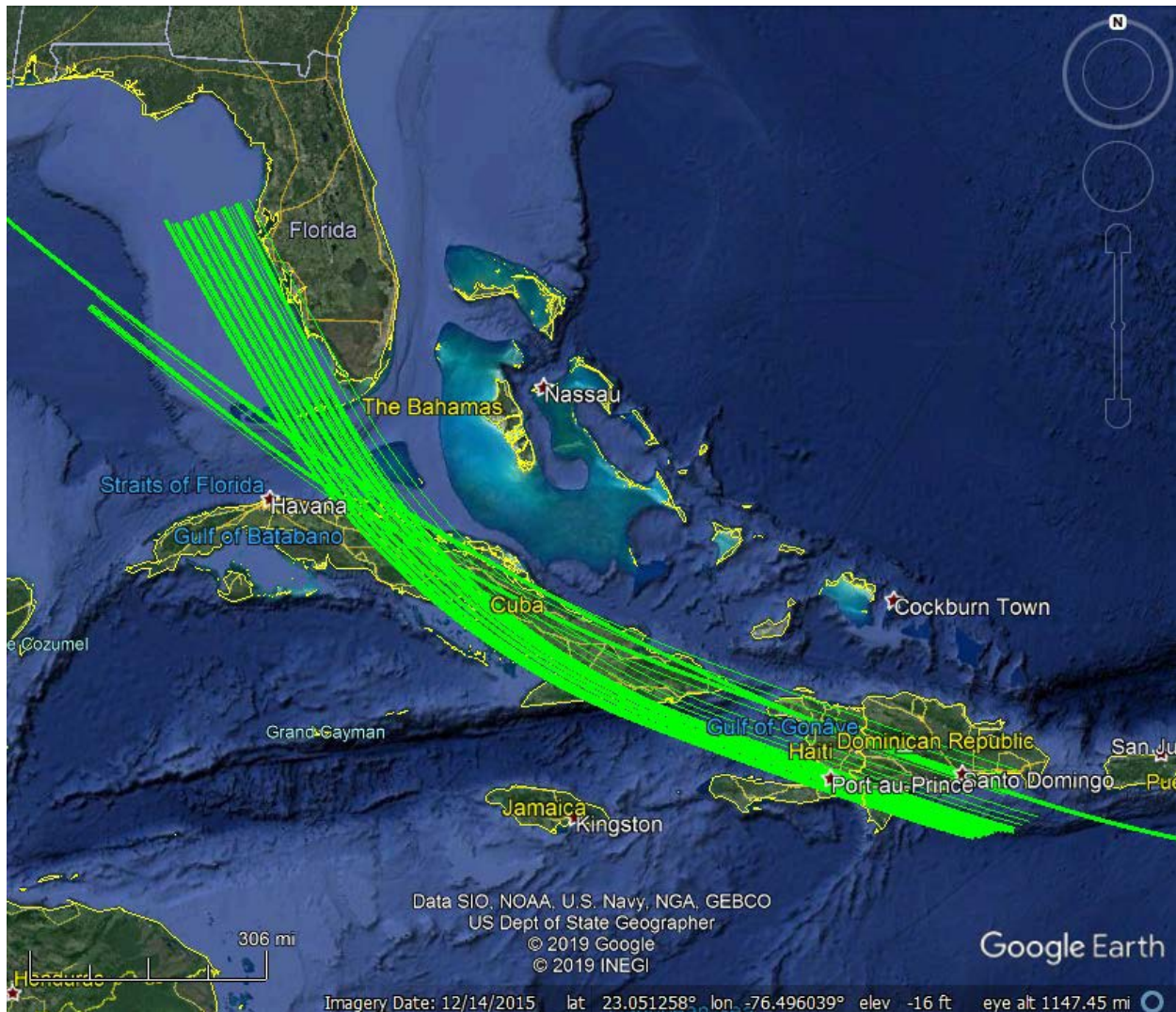


Figure 5. Example FEMA production synthetic storm tracks that interacted with land masses but did not include attenuation due to this interaction.

Addressed Through Use of Alternative Methodology, Data, and New or Updated Analysis

The issues related to the use of one CRP not representative of the Keys for establishing the storm climatology, the use of a spatially constant storm rate, and the lack of synthetic storm attenuation due to land masses were partially addressed with this reanalysis through the use of an alternative methodology.

Storm rates were reassessed using a spatially varying approach which gives a more accurate assessment of the rate of storms which would impact the Keys. The use of this approach is more scientifically correct and provides a better characterization of storm rates in the Florida Keys. The storm rate variability developed using this approach and resulting adjustment factor applied to FEMA’s spatially constant storm



rate is shown in Figure 6 for the east coast storm set. The analysis is further detailed in Appendix B along with storm adjustment rate factors for the west coast storm set. The use of this approach is also consistent with that applied in FEMA’s adjacent Southwest Florida RiskMap study.

The fact that the synthetic storms did not include attenuation caused by land masses was not addressed and would have exceeded the City’s study capacity and time constraints to resolve. Through the determination of the spatially varied storm rates and their application, the frequency of storm impacts in the Keys was more accurately assessed.

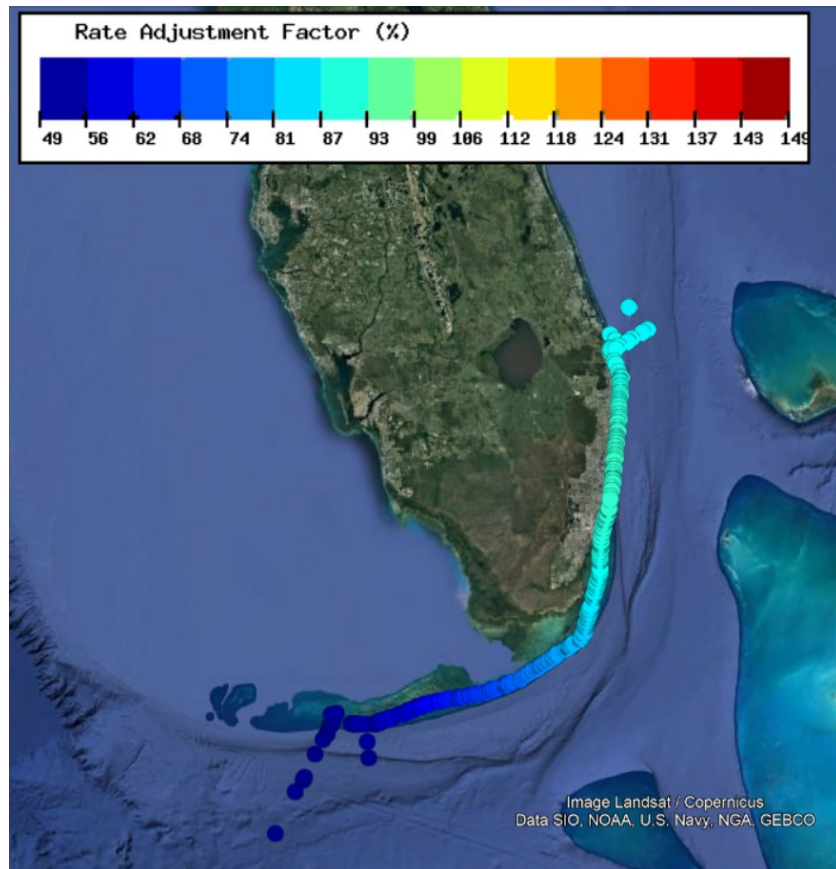


Figure 6. Storm rate adjustment factors (%) developed as part of this appeal for the east storm population JPM-OS storms.

4.2 STATISTICAL ANALYSIS OF STORM SETS, LOW-FREQUENCY WATER LEVELS AND WAVES

Description of Issue(s)

A non-standard analysis that combined storm sets approaching from the east and west was used by FEMA to develop the 1% water levels. FEMA applied a combined probability analysis (CPA) which assumes the storm sets are independent even though both storm sets have Atlantic and Caribbean genesis storms, potentially leading to inflated 1% water levels. Additionally, the study did not include measurement error



in the statistical analysis, which is inconsistent with other FEMA RiskMap studies conducted on the West coast of Florida and in other FEMA regions.

The East and West storm sets were treated as independent populations, the frequency of occurrence of surge for each storm set was statistically determined, and the frequency of occurrence of surge for the two sets were then combined. Concerns were raised about using this approach by FEMA’s Technical Steering Committee review team as this differs from how statistical water levels have been determined in the other adjacent FEMA studies. It was characterized as a “non-standard approach” in comments made by FEMA’s Steering Committee (see Appendix D).

Reviewer Comment:

“Please consider adding references to journal articles (peer reviewed) on this non-standard approach to combining East and West coast storm results down in FL Keys. Any documentation on methodology development would be helpful supporting its use on SFL study results.”

While FEMA did include references for the combined probability analysis in their documentation, none of the references suggest this approach be applied for statistically evaluating two sets of tropical cyclones sourced from the same physical processes and occurring in the same season.

This type of combined frequency analysis is typically applied when storm events can be classified as being independent and belong to different classes depending on physical processes or time of year¹. Such is the case for: 1) riverine (high discharge/rainfall) and coastal (storm surge) flood events, or 2) tropical and extratropical storm events. These different types of events are typically statistically analyzed separately using different statistical models (or distribution functions) that may be appropriate for each respective group.

The treatment of the East and West storm sets is not appropriate given that their generation source and time of year are the same. The storm sets could have been statistically evaluated similar to what has been done in other adjacent Florida FEMA studies with different types of storm populations (i.e., landfalling, bypassing, and land-exiting storms). It is notable that an analysis including spatially variable storm rates coupled with an appropriate analysis of storm track heading would preclude the need to separate the storms into east and west populations.

In the statistical analysis of water levels, a number of uncertainty terms are included, and larger uncertainty terms result in higher 1.0- and 0.2-percent annual chance water levels. FEMA included an uncertainty term for the model validation based on how well the surge model was able to reproduce high water mark (HWM) measurements in simulations of (5) historical storms. Typically, the amount of error that is inherent in the measurements is calculated and this is included to reduce the model validation uncertainty term. FEMA states in IDS 3 Section 3 that the density of the HWM measurements did not allow for the measurement error to be appropriately calculated, and as such, the measurement error was set to zero (0).

¹ Bardsley, W. E. (2016) Cautionary note on multicomponent flood distributions for annual maxima. *Hydrol. Process.*, 30: 3730– 3732. doi: 10.1002/hyp.10886.



Not calculating or using any measurement error in developing the uncertainty terms applied in the statistical analysis deviates from standard practice and the majority of FEMA’s coastal studies. In FEMA’s adjacent West Florida (WFL) study, the study team also concluded there were not enough measurements to compute measurement error, and thus used the measurement error computed from FEMA’s Mississippi study. Assuming some level of error is a more correct approach than assuming there is zero error in the measurements.

There are a number of sources of error in the HWM measurements. These include equipment error, or accuracy of measurement (For example, the HWM report for Wilma (URS, 2006) states survey vertical accuracy of 0.25 feet), human error (applying correct measurement techniques), and indistinction in the type of HWM due to local influences (i.e., inside vs. outside marks, debris line vs. silt line, entrapped debris caused a local fluctuation in water level, etc.).

In correspondence received on June 11, 2020 regarding this point, FEMA states *“This is consistent with the ECCFL and GANEFL studies, which did not include a measurement error.”* While this may be consistent with the East Coast studies conducted by the same set of FEMA consultants, those other studies were never challenged with appeals as to whether applying zero measurement error is correct. The use of no measurement error due to lack of sufficient or poor-quality data indicates the statistical water levels are technically incorrect.

FEMA’s Technical Steering Committee (comments relevant to this appeal extracted and provided in Appendix D) commented in reference to the statement that the density of the HWM measurements did not allow for the measurement error to be appropriately calculated:

“This is a common yet relatively unsubstantiated statement of convenience for SFL and other FL studies.”

In the production team’s response, there is no clarity given on whether the HWM data were evaluated for estimating measurement error (i.e., what/how many points could be used for this analysis?). It is acknowledged in their response, however, that changing the error term has a direct and potentially significant impact on the statistical analysis and study results.

Addressed Through Use of Alternative Methodology, Data, and New or Updated Analysis

These issues related to the non-standard use of a CPA for statistically analyzing multiple sets of tropical cyclones and the lack of measurement error in determining the uncertainty term used in the analysis were partially addressed in this appeal and reanalysis. Hurricane Irma was included as a validation storm which provided additional recent and relevant data for the Florida Keys. This allowed for measurement error associated with collected high-water marks to be assessed. Details of the additional model validation for Irma and measurement error analysis are provided in Appendix A. The separation of ‘East’ and ‘West’ storm sets and the use of the combined probability analysis were not directly addressed as this essentially would require a complete re-study, redefinition of storm parameter distributions, and redevelopment of the entire JPM-OS synthetic storm set.



4.3 WAVE MODEL VALIDATION

Description of Issue(s)

In IDS Report 1 Section 3, FEMA concludes there are no observations of wave data within the study area for the purposes of model validation. The lack of data does not allow for confidence in the wave model’s ability to simulate storm-induced wave conditions for the Florida Keys with its complexity and unique characteristics: chain of islands with exposure from both Gulf and Atlantic generated wave conditions and protected on both sides by extensive reef features.

As part of the City’s review, wave measurement data offshore of Monroe County were identified that captured conditions during Hurricane Andrew (1992), as well as tropical storm Gordon (1994) and Hurricane Erin (1995). It is not clear why these data were not used for model validation. FEMA stated in correspondence received on June 11, 2020, that Erin and Gordon “did not meet enough criteria to be included in the list of candidate validation storms (as shown in Table 5.1 of the SFL IDS 1, Section 3 report)”; however, the criteria for storm selection did not include wave data availability as it was previously concluded that no wave data existed near the South Florida study area. If FEMA had included wave data availability in the screening criteria for validation storms, these storms may have been selected. Alternatively, these storms could have been considered separately for wave model validation alone.

Table 2. Available wave data within the South Florida Study Region.

NDBC Wave Station	Data Availability
42025 24.900N 80.4W	Oct 1991 – Feb 1993 Aug 1993 – Jun 1994 Jan 1995 – Jul 1995
42037 24.500N 81.4W	Apr 1994 – Dec 1995
42080 24.396N 81.934W	Dec 2007 – Mar 2008

Additionally, FEMA could have elected to collect wave measurements over the course of the multi-year study. This is the only FEMA coastal study in which there has been no wave data for the purposes of model validation and the only FEMA study the City’s team is aware of that has been performed without wave model validation.

Again, this indicates a lack of sufficient or poor-quality data in order to determine whether output from the wave model is technically incorrect.

A comparison was made between wave data measured at NOAA’s NDBC buoy 42025 during Hurricane Andrew and FEMA’s model output from its model hindcast of Hurricane Andrew, as shown in Figure 7. It shows FEMA’s model overpredicts the wave height at this location by approximately 2 meters (6.5 feet). This comparison does not provide confidence in the model’s ability to predict wave conditions.

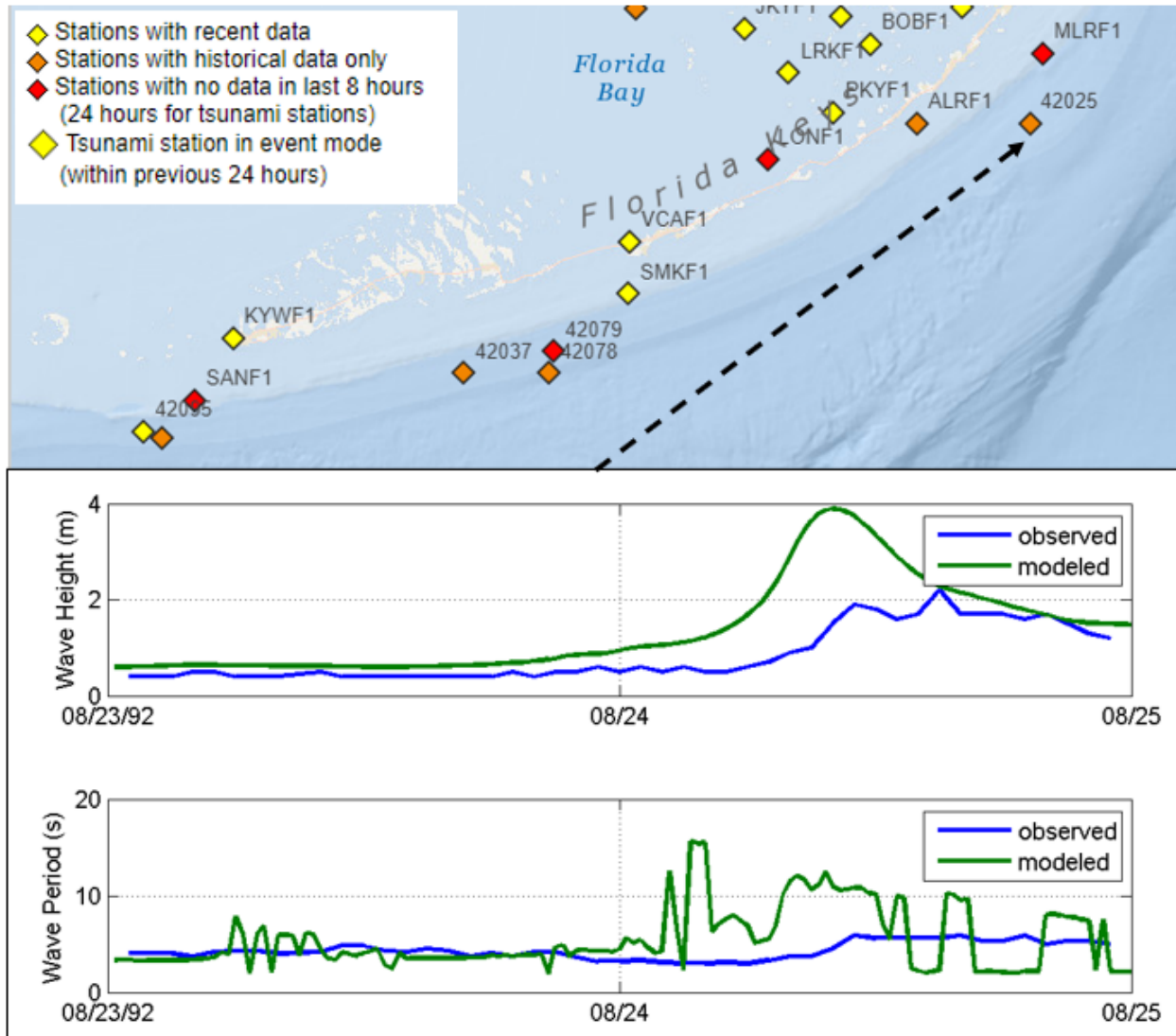


Figure 7. Time series comparison of NOAA-observed wave conditions during Hurricane Andrew with FEMA's modeled conditions at NDBC station 42025.

Addressed Through Use of Alternative Methodology, Data, and New or Updated Analysis

The lack of wave model validation was not addressed through additional reanalysis. The acquisition of additional storm wind and pressure fields and additional model validation would require additional funds and time that went beyond what could be accommodated by the City in this appeal.



4.4 HYDRODYNAMIC/WAVE MODEL MESH RESOLUTION

Description of Issue(s)

Issues related to the ADCIRC+SWAN hydrodynamic/wave model mesh were identified at seven (7) channel locations throughout the Keys. The model mesh was not resolved to sufficiently represent the hydraulic capacity of the channels and allow conveyance of storm surge and waves during simulated storms. These were errors or oversights made in the mesh developed for the Keys. This issue was communicated to FEMA in correspondence dated May 4, 2020. FEMA responded in their June 11, 2020 correspondence that these were not errors but rather the modelers chose to not fully represent these channels because the target mesh resolution (distance between model nodes) for the Florida Keys was 250 feet. Additionally, FEMA stated that, “The request to improve conveyance pertains to a higher level of detail analysis that falls outside of current scope of the Flood Study.”

Table 3 lists the seven (7) channels that lacked sufficient resolution in the model along with the channel widths. Figures 8 and 9 show examples of channels in the Keys that were not fully represented (further examples are presented in Appendix A, Attachment B). Most of these channels have widths at or greater than 250 feet, the target resolution. Even if these channels are smaller than the target resolution, consideration should have been given to represent the primary channels in and around the Keys to an appropriate level of resolution to be technically correct in conveying storm surge. The City does not believe this falls outside the scope of FEMA’s study.

Table 3. Channels not sufficiently represented in FEMA’s model

Channel Name	Approximate Channel Width (ft)
Fleming Key Cut	284
Cow Key Channel	199
North Harris Channel	226
Harris Channel	373
Sister Creek	180
Lignumvitae Channel	780
Tavernier Creek	249

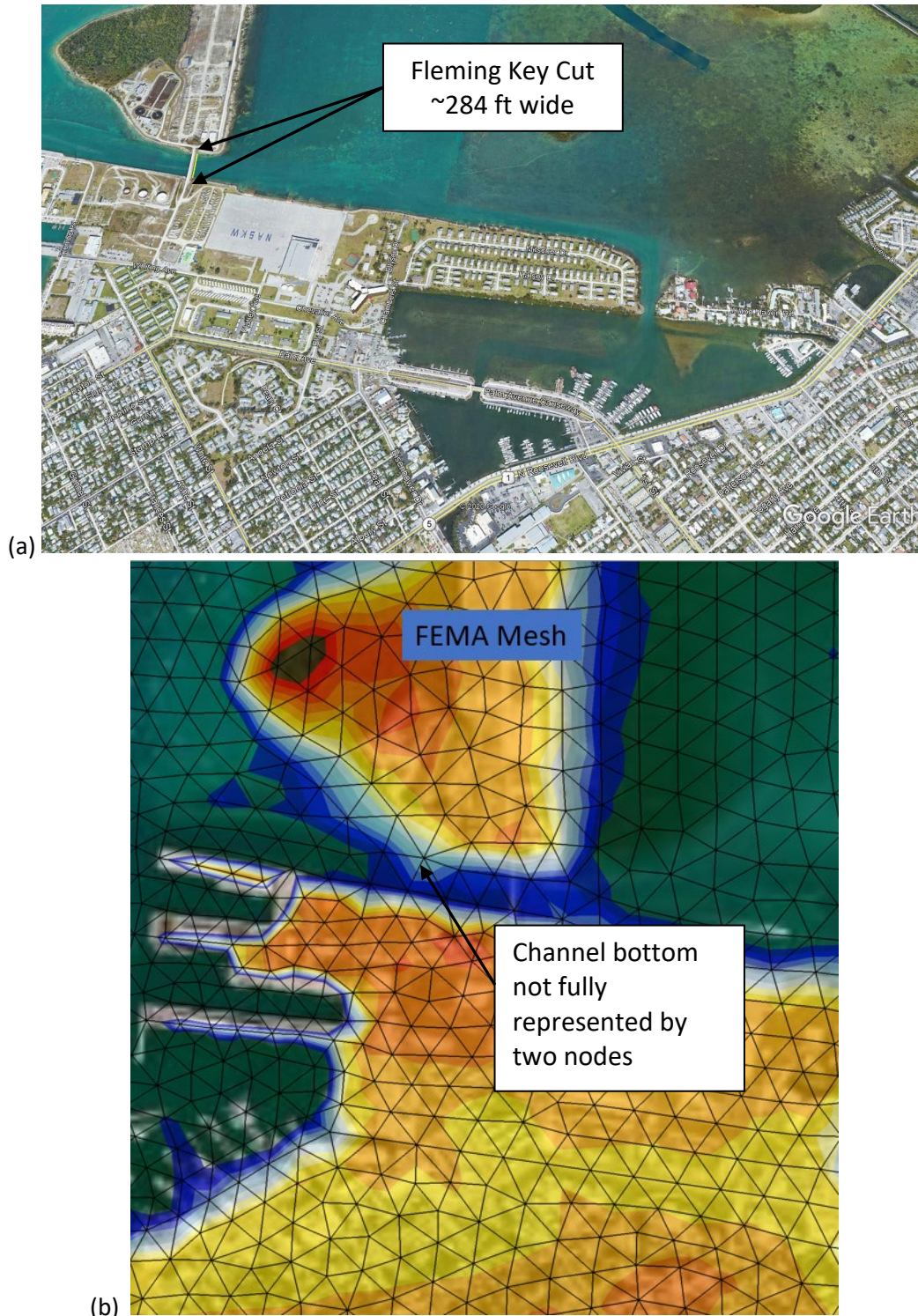


Figure 8. Example of lack of sufficient model resolution – Fleming Key Cut. Panel (a) shows aerial image and panel (b) shows the model mesh overlaid on color contours of elevation (yellow to red colors represent overland areas > 0 ft in elevation relative to NAVD88).

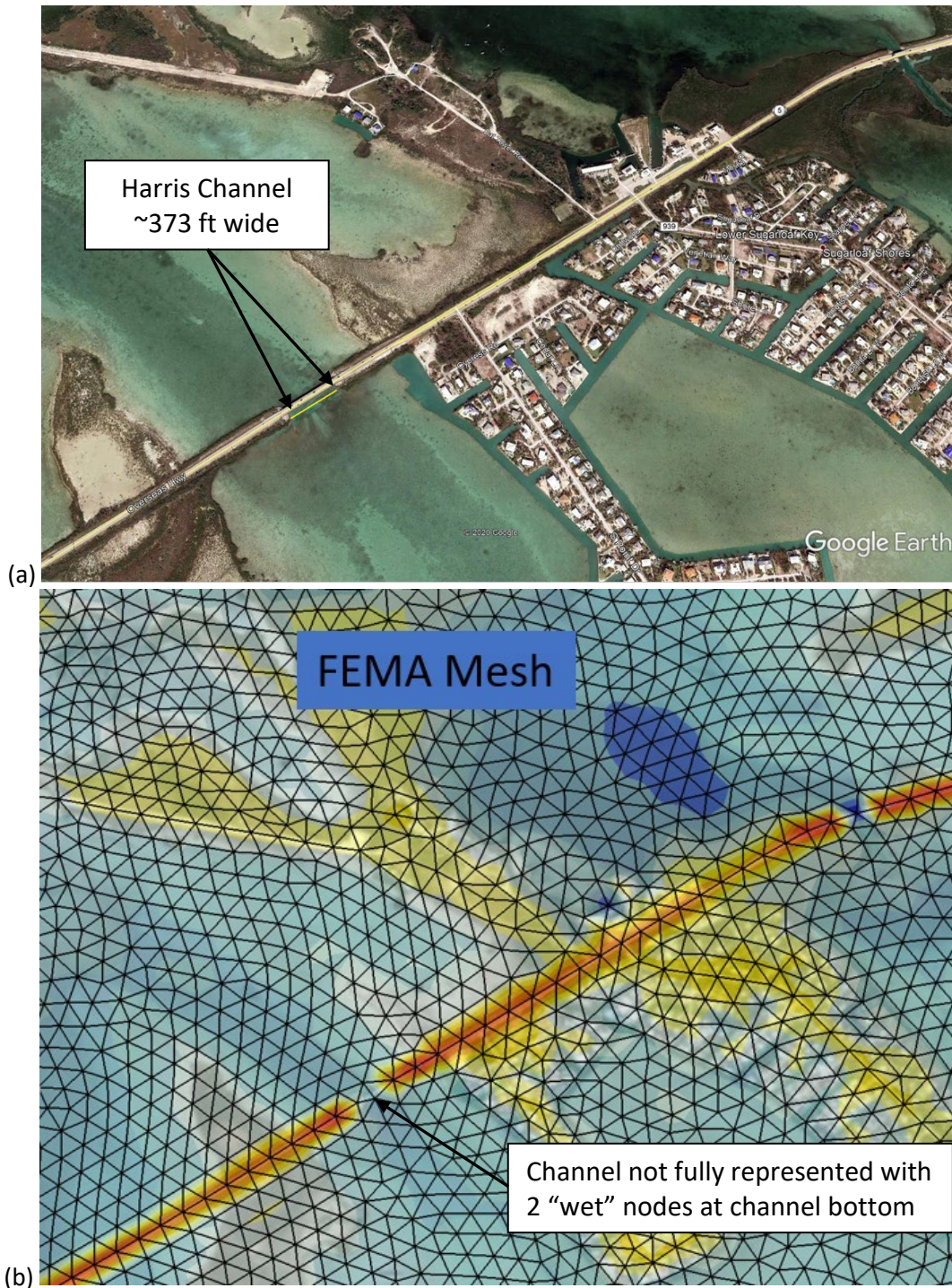


Figure 9. Example of lack of sufficient model resolution – Harris Channel. Panel (a) shows aerial image and panel (b) shows the model mesh overlaid on color contours of elevation (yellow to red colors represent overland areas > 0 ft in elevation relative to NAVD88).



As part of the City’s review, the storm surge and wave model resolution was increased where it was found to be insufficient at the channels listed in Table 3. This resulted in only 75 additional nodes added to the model mesh (total of 2,249,168 nodes). A single production storm was first run (storm 113) to assess the potential impacts of the lack of resolution. Storm 113 was selected as it tracked within the middle portion of the Keys and had a substantial contribution to the 1%-annual-chance water levels developed by FEMA. Comparisons with FEMA’s results showed local differences in maximum storm surge on the order of 0.4 to 1.6 feet (see Appendix A, Attachment B for further details). This indicates the importance of adequately resolving these channels, and that FEMA’s model results are scientifically incorrect because the model resolution used was inappropriate.

Addressed Through Use of Alternative Methodology, Data, and New or Updated Analysis

This issue related to insufficient model resolution and representation of hydraulic pathways was addressed by increasing the storm surge and wave model resolution where it was found to be insufficient. The updated model was revalidated and then used to simulate a subset (46 storms) of FEMA’s defined JPM-OS synthetic storm set. Further details are provided in Appendix A. The results from these storm runs were then incorporated into the statistical analysis of water levels and waves that affect the 1%-annual-chance base flood elevations. Updated overland wave modeling and floodplain mapping were then conducted using these updated 1% wave and water levels, as detailed in Appendix C.

4.5 HYDRODYNAMIC/WAVE MODEL PARAMETERIZATION OF REEFS

Description of Issue(s)

When characterizing reefs in the ADCIRC+SWAN hydrodynamic/wave model, FEMA used friction values at the lower end of what is recommended by the scientific literature. Since friction created by the reefs acts to dissipate the amount of wave energy reaching the shoreline, this issue has a significant impact on the predicted storm wave conditions, wave setup, surge, and the subsequent overland wave modeling and flood zone mapping.

This issue was communicated to FEMA in correspondence dated May 4, 2020, and the question was asked what FEMA used to establish the friction value applied to reefs since reef features were not specifically called out with friction values documented in FEMA’s IDS reports. FEMA responded in their June 11, 2020 correspondence that “*Manning’s n values corresponding to seagrass and land use derived from hydraulic roughness values found in Nelson (1996) Hydraulic Roughness of Coral Reef Platforms*”.

It is unclear why this was not included in FEMA’s IDS report and only clarified after bringing it to FEMA’s attention, especially given the number of reviews that were conducted as part of FEMA’s study.

The City’s review of recent studies relevant for determining bottom roughness coefficients for reef features indicates the appropriate range in Manning’s n frictional coefficients for reefs is from 0.04 to 0.35 (further detailed in Appendix A, Attachment A). FEMA specified a Manning’s n value of 0.035 to 0.05 for reefs which is below or at the low end of the applicable range for reefs. However, the study provided by FEMA (Nelson, 1996) also suggests using a higher frictional value than FEMA applied for reefs.

As part of the City’s review, the model’s sensitivity to the frictional coefficient was assessed by increasing the Manning’s n value for reefs from 0.035-0.05 to 0.1. Again, a single production storm was run (storm



113) to assess the potential impacts on model-predicted water levels and wave conditions. Comparisons with FEMA’s results showed regional differences extending out from the storm track in maximum storm surge on the order of 0.4 to 3.0 feet (see Figure 10). In addition, peak wave heights occurring during the storm were reduced by 0.5 to 0.9 feet and this reduction was shown to occur across a broader extent of the Keys, as shown in Figure 11.

This indicates the model’s sensitivity to the frictional coefficient applied to reef features. Given the lack of wave model validation (discussed in Section 4.3), FEMA’s applied frictional coefficient for reefs is not appropriate based on the latest scientific literature. Applying a mean or median bottom roughness value based on the prior studies founded on field studies is more scientifically correct in this instance.

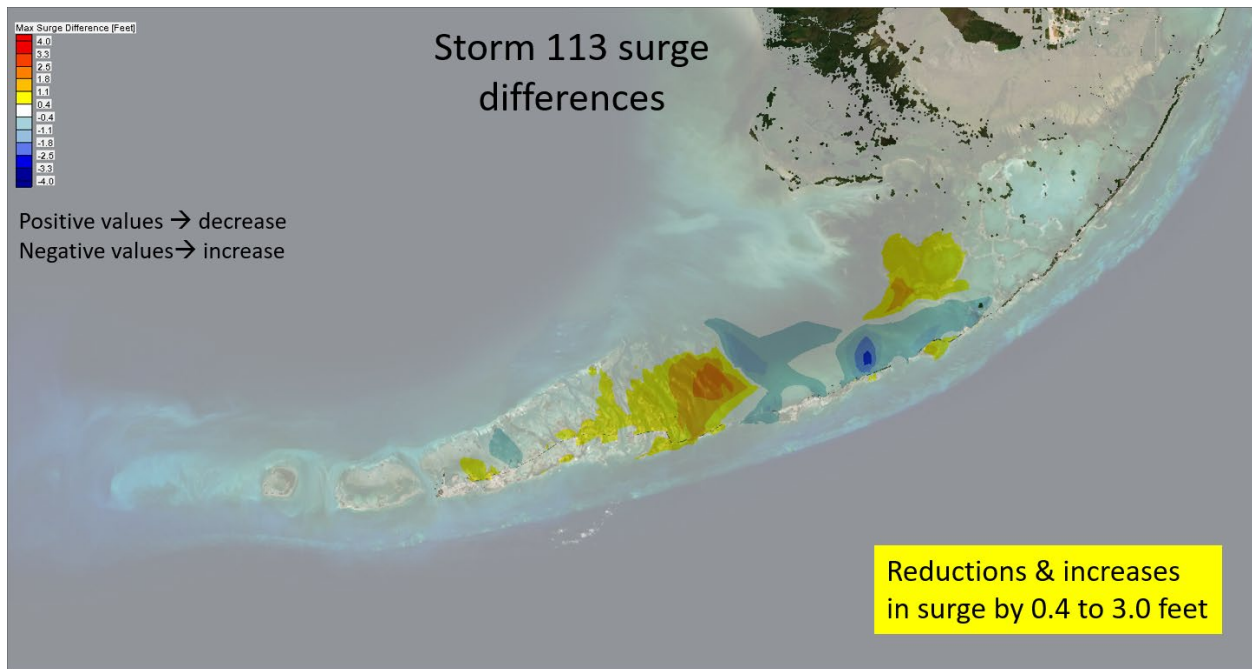


Figure 10. Differences in maximum storm surge between FEMA’s model and the updated model configuration for Production storm 113.

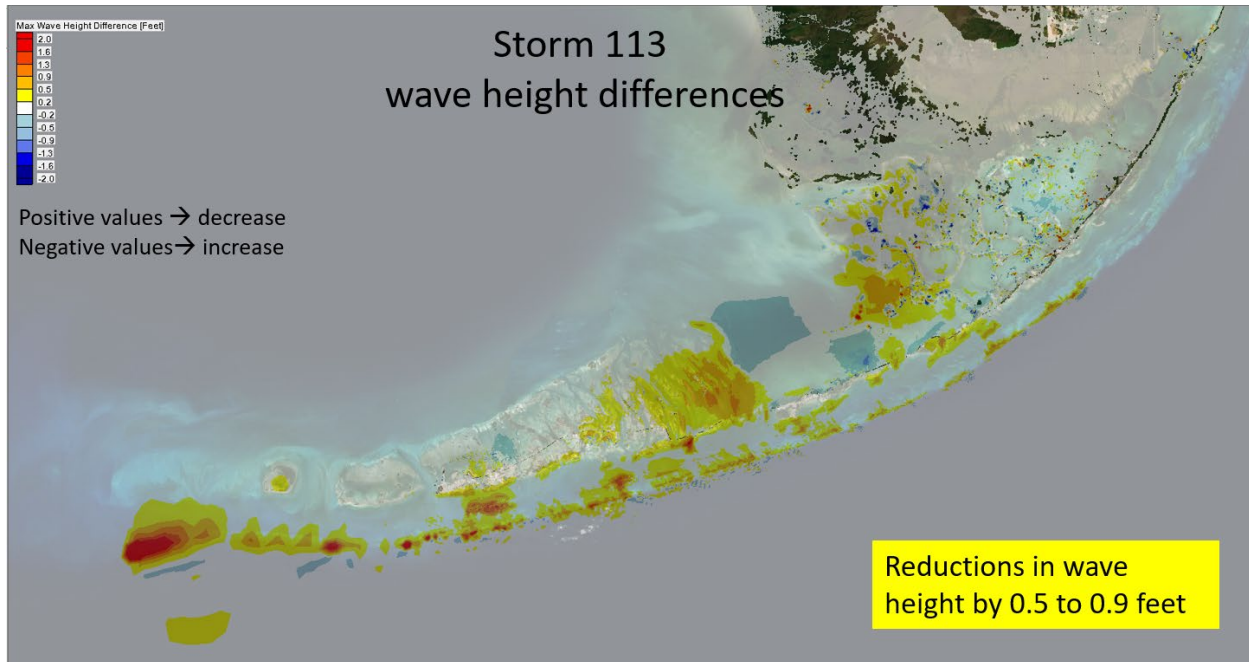


Figure 11. Differences in maximum wave height between FEMA’s model and the updated model configuration for Production storm 113.

Addressed Through Use of Alternative Methodology, Data, and New or Updated Analysis

The inappropriate assumptions used for characterization of reef features was addressed by adjusting the roughness parameter assigned to reefs in and around the Keys to a more appropriate median value (Manning’s n value of 0.07). Additionally, the City updated the extent of the reefs represented in the model using the latest Florida Fish and Wildlife Conservation Commission Unified Reef Map (Baumstark, 2013). See Appendix A, Attachment A for details on the literature review and application of a medium value of bottom roughness value for reef features. The updated model was revalidated and then used to simulate a subset (46 storms) of FEMA’s defined synthetic storm set (see Appendix A). The results from these storm runs were then incorporated into the statistical analysis of water levels and waves that affect the 1%-annual-chance base flood elevations. Updated overland wave modeling and floodplain mapping were then conducted using these updated 1% wave and water levels, as detailed in Appendix C).



5.0 SUMMARY

Woods Hole Group completed a reanalysis of FEMA’s December 2019 RiskMap study for the City of Key West with Ransom Consulting working as a subconsultant. The scope of the reanalysis was based on earlier reviews conducted by Woods Hole Group and Ransom Consulting which identified the primary areas of concern identified in FEMA’s RiskMap study:

- 1) Storm Climatology and Selection for Florida Keys,
- 2) Statistical Analysis of Storm Sets, Low-Frequency Water Levels and Waves,
- 3) Wave Model Validation,
- 4) Hydrodynamic/Wave Model Mesh Resolution, and
- 5) Hydrodynamic/Wave Model Parameterization of Reefs.

These areas of concern were identified because of (a) the use of a non-standard approach, (b) inconsistencies in methodology with other FEMA Coastal RiskMap studies, (c) discrepancies between the study’s documentation and the analyses, or (d) errors made in the analyses.

Woods Hole Group’s reviews and reanalysis concluded that FEMA’s proposed flood hazard determinations are both technically and scientifically incorrect. FEMA did not appropriately characterize flood hazards in the City due to the technical approach and assumptions that were applied and because FEMA attempted to include the Florida Keys in its regional study that was better suited for the mainland Florida Counties (Miami-Dade, Broward, and Palm Beach).

The City’s reanalysis is more applicable for the Florida Keys considering its geography (over 100 miles of shoreline extending from the mainland), its unique characteristics (chain of islands interconnected by myriad of channels with extensive nearshore reefs) and makes use of better and more recent data such as Hurricane Irma.

This appeal of FEMA’s Preliminary FIRMs is predicated on the following:

- In developing the storm climatology, FEMA used a single CRP in Miami-Dade County which was not representative of storms impacting the Keys and then applied a spatially constant storm rate. The City’s restudy included a revised approach in developing storm rates which is more appropriate for the Keys. The approach allows for a spatially varied storm rate which is more accurate given the extensive shoreline of the Keys (both Gulf and Atlantic) and is an improvement to the approach used by FEMA.
- Hurricane Irma was included in the City’s reanalysis which provided more data in Monroe County for model validation and for determining measurement error. This helped to reduce the amount of uncertainty used in the statistical analysis for determining the 1%-annual-chance stillwater elevation. This is an improvement to FEMA’s study in that the most recent available data is being applied. Hurricane Irma was the most intense storm to impact the Keys in recent history and it provided a wealth of data. In addition, this helped to address a deficiency in FEMA’s study in which they did not account for any error in the field measurement of high-water marks.



- FEMA did not conduct any wave model validation. The City’s review did reveal the availability of wave data that FEMA could have utilized. No other FEMA study that the City’s team is aware of has been performed without wave model validation.
- FEMA’s coupled hydrodynamic/wave model lacked the resolution required to sufficiently represent the hydraulic capacity of seven (7) channels in and around the Keys. The City’s restudy used a revised storm surge model which included a better representation of the small channel features in the Keys. This is an improvement to FEMA’s model because not all waterways were sufficiently represented in FEMA’s model to appropriately convey storm surge.
- The latest available research data was used to sufficiently parameterize the reef features in the model which help to dissipate wave energy in and around the Keys and have a significant impact on the simulated storm waves and water levels. A review of recent studies showed FEMA used a bottom roughness value (Manning’s n) for reefs that was below or at the low end of the applicable range found in documented field studies. Given the lack of wave model validation and the sensitivity of the model to the applied friction, the use of a mean or median value for reefs is more appropriate. The City’s restudy used a revised storm surge model with a more appropriate characterization of the reefs surrounding the Keys using the latest available reef extents from the Florida Fish and Wildlife Conservation Commission.
- The revised storm surge model with increased resolution and updated friction applied for reef features was used to simulate a subset of the synthetic JPM-OS storms (46 in total) which were then incorporated into statistical analysis of water levels and waves.
- The combination of these revisions resulted in a lowering of the 1%-annual-chance stillwater elevation in Key West by 0.5 to 1.1 feet.
- The revisions also resulted in a lowering of the 1%-annual-chance wave heights used in the overland modeling of flood hazards in Key West by 0.2 to 0.7 feet.

Upon completion of the reanalysis, Woods Hole Group remapped the flood zones within the City limits which showed a 1-foot reduction in the base flood elevation (BFE) for the majority of the City and some areas with a 2-foot reduction in BFE. Some areas within the City did not have a change in BFE with the map updates. See Figure 12 for the updated mapping and Figure 13 denotes areas where there are changes in BFE with the updated mapping.

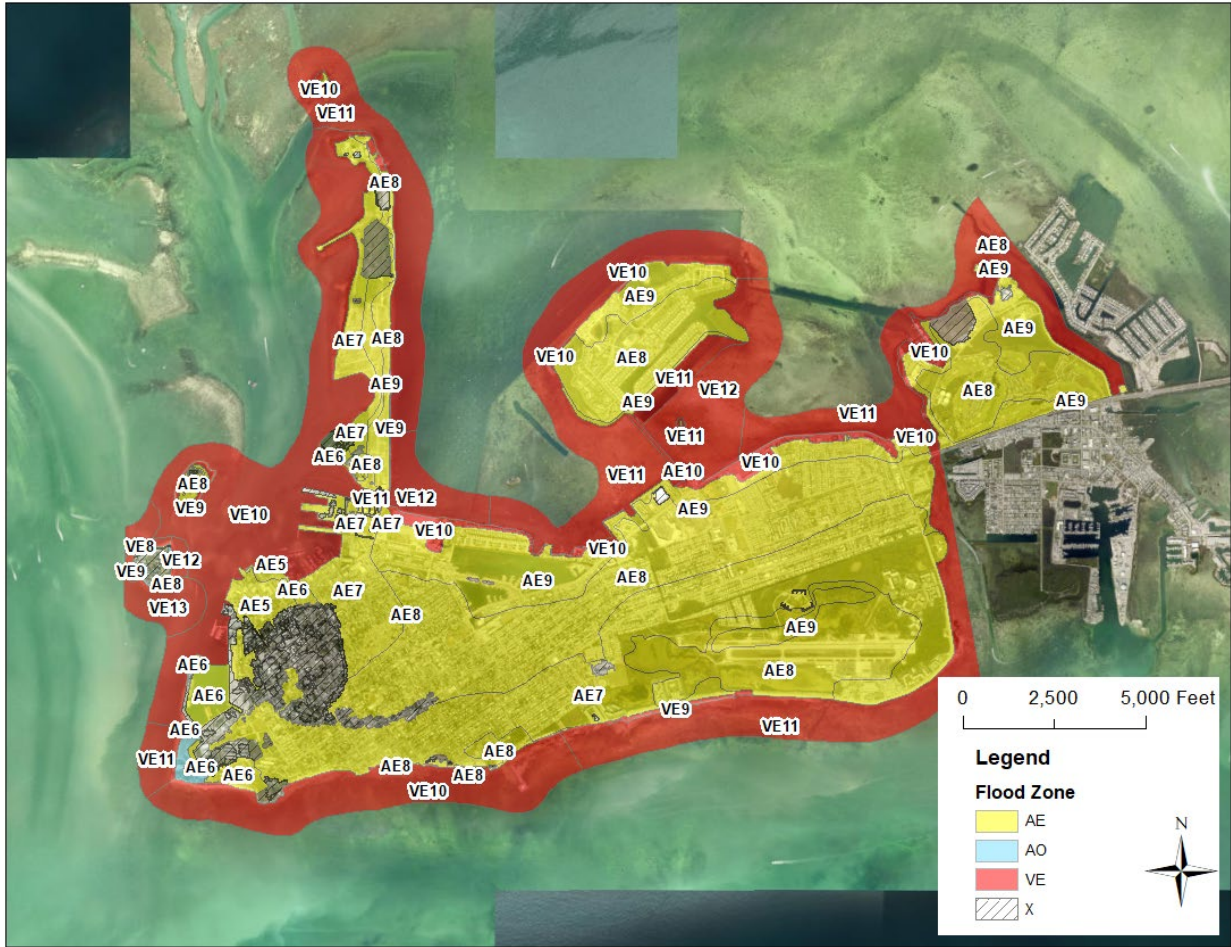


Figure 12. Revised flood zones for Key West, FL, resulting from this appeal.

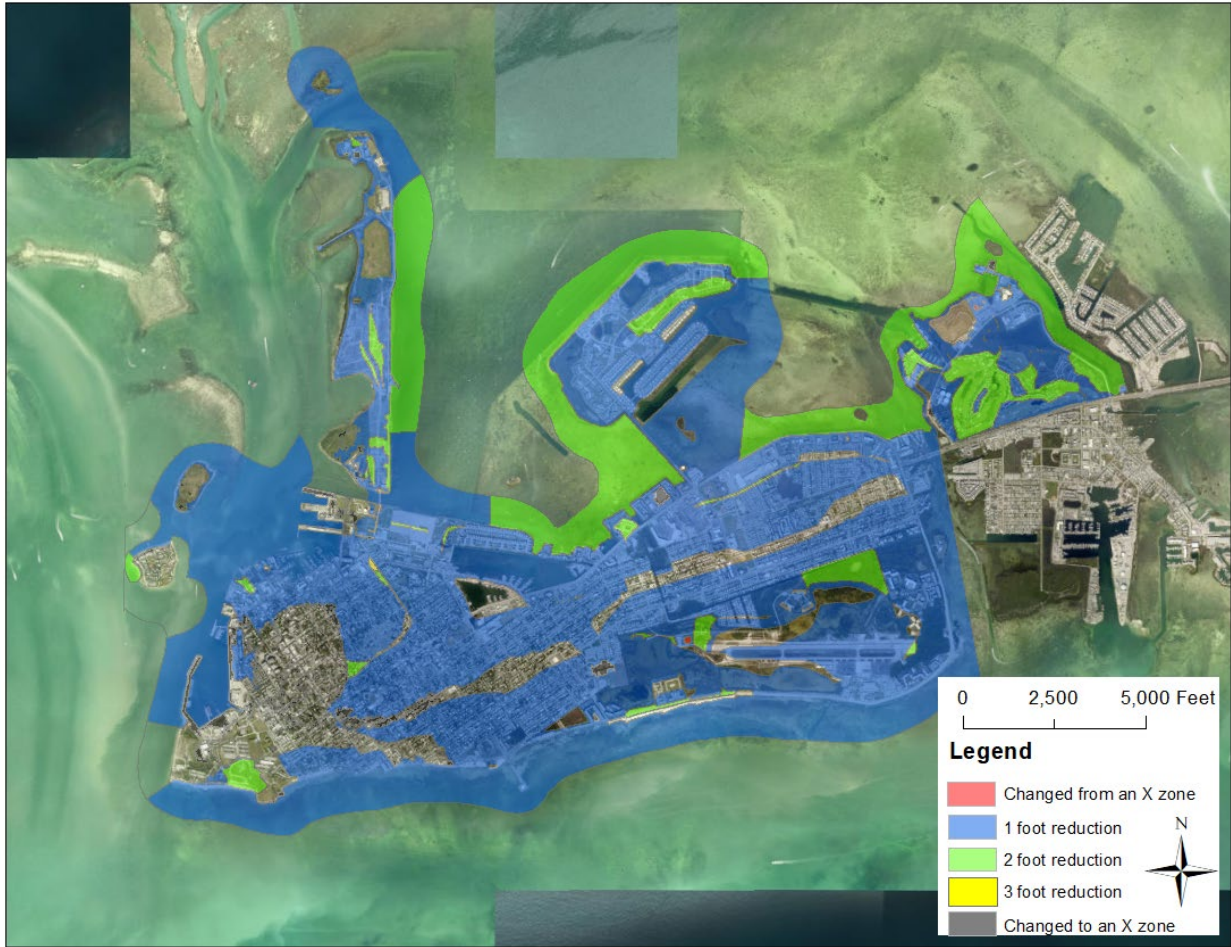


Figure 13. Changes in flood zones/base flood elevations for Key West, FL, with revised mapping resulting from this appeal.



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- Baumstark, R. D. "Coordinated coral and hardbottom ecosystem mapping, monitoring and management." Florida Fish and Wildlife Conservation Commission, St. Petersburg, FL (2013).
- Nelson, R.C., Hydraulic roughness of coral reef platforms, Applied Ocean Research, Volume 18, Issue 5, 1996, Pages 265-274, ISSN 0141-1187, [https://doi.org/10.1016/S0141-1187\(97\)00006-0](https://doi.org/10.1016/S0141-1187(97)00006-0).
- URS Group, Inc. 2006. Hurricane Wilma Rapid Response Florida Coastal High-Water Mark (CHWM) Collection (FEMA-1609-DR-FL). Hazard Mitigation Technical Assistance Program Contract No. EMW-2000-CO-0247 Task Order 460. Prepared for the Federal Emergency Management Agency (FEMA). Submitted March 30, 2006.



6.0 APPENDICES

APPENDIX A – STORM SURGE MODEL REVISIONS, UPDATED MODEL VALIDATION, & PRODUCTION STORMS

APPENDIX B – RE-EVALUATION OF SPATIALLY VARIABLE HISTORIC STORM RECURRENCE RATES AND STATISTICAL ANALYSIS/JPM-OS INTEGRATION

APPENDIX C – KEY WEST, FL, OVERLAND MODELING AND FLOODPLAIN MAPPING

APPENDIX D –FEMA STEERING COMMITTEE QAQC COMMENTS (SELECT COMMENTS EXTRACTED AND PROVIDED AS SEPARATE DOCUMENT)

APPENDIX E – PRIOR CORRESPONDENCE

APPENDIX F – STUDY CERTIFICATION

APPENDIX G – ELECTRONIC DATA SUBMITTAL - TSDNS