KCC US Flood Reference Model Version 2.0

FCHLPM Public Meeting

November 7, 2024

KC &CO

The Innovation and Technology Leader in Weather, Climate, and Catastrophe Risk Modeling

KCC Response to Deficiencies

- All deficiencies were addressed with corrections or clarifications in the KCC submission document and were reviewed by the Professional Team. All changes since the initial submission have been documented in the KCC revision letters provided with the revised submissions.

Revisions to currently-accepted model

- Event Catalog Module updates:
  - Inclusion of 2019-2021 events
  - Consideration of climate change impacts on hurricane intensity distributions
  - Updated storm tracks including re-intensification over the Gulf of Mexico
  - Updated central pressure calculation using storm relative maximum wind speed
- Intensity Footprint Module updates:
  - Updated mean sea level height in coastal flood footprint generation
  - Refined treatment of storm surge heights for storm tracks exiting land
  - Inclusion of urban drainage system impacts on water balance for impervious surfaces
  - Updated treatment of input precipitation data to hourly
  - Updated soil and land surface characteristics that determine the water balance for inland flooding
  - Inclusion of the potential for floodplain widths to expand during the calculation of floodplain water depth
- Vulnerability Module updates:
  - Updated vulnerability functions when building year-built is unknown based on updated building year-built inventory distribution.
  - Updated vulnerability functions for commercial residential, renter, and condo occupancy types when building height is unknown.
  - Updated vulnerability regions based on newer NFIP data.
  - Updated first floor height assignments when first floor height and foundation type are unknown.
- Other Changes:
  - ZIP Code updates:
    - Updated ZIP codes and related databases
  - KCC US Industry Exposure Database update:
    - Demand surge factors have been updated to reflect the increased property values in the 2022 KCC Industry Exposure Database

Effect of Revisions on Loss Costs and PML (Hazard)

Model Update	Impacts on Model Results
Climate change impacts on hurricane intensities	• General loss increase in coastal areas due to higher storm surge from more intense tropical cyclones
Accounting for sea-level rise	• Increases in coastal flood extents and depths leading to higher losses in coastal areas
Exiting storm surge heights	• Decreases in coastal losses in areas impacted by exiting storms
Explicit urban drainage	• Less frequent minor surface flooding in urban areas but greater impacts during more extreme events • Enhanced runoff into channels flowing through urban areas • Causes enhanced runoff in upstream areas of St. Johns River and more frequent flooding of the channel as it flows through Lake County
Hourly precipitation	• More realistic and generally higher surface flooding in urban areas where high rainfall rates can overwhelm urban drainage
Catchment-level surface and sub-surface characteristics	• More accurate representation of surface and riverine flooding that captures the spatial variability of land cover and soil characteristics in the flood model parameters • Leads to large local differences in losses between V1.0 and V2.0 while overall event losses remain similar in total • For example, reduced runoff in the sandy soil of the east St. Mary's River watershed causes a decrease in surface flooding there relative to the currently accepted model
Dynamic floodplain width	• Leads to a reduction in flood impacts for locations near rivers but at elevations high enough to only be impacted by the more extreme events • This effect is greatest for low-slope floodplains that are common in Florida

Effect of Revisions on Loss Costs and PML (Vulnerability)

Model Update	Impacts on Model Results
Unknown year-built vulnerability functions	General loss decrease when year-built is unknown
Unknown building height vulnerability functions for commercial residential	General loss increase for commercial residential when building height is unknown
Update vulnerability region by CRS	Change loss by community
Update the assignment of first floor height	Loss decrease for the buildings when first floor height is unknown, foundation type is unknown, and year-built band is Pre-FIRM (Flood Insurance Rating Map)

KCC Meets Standard GF-1: Scope of the Flood Model and Its Implementation

- All model components of the Karen Clark & Company (KCC) US Flood Reference Model utilize scientific data and engineering analyses to capture the damage due to flood events and are consistent with the observed climatology and the current state of research. The loss costs and probable maximum loss levels that are output by the model reflect the primary damage to insured personal residential property from flood events.

- KCC employs documented procedures to ensure the continuity and accuracy of databases, data files, computer source code, presentation materials, scientific and technical literature, and internal documentation, including all materials shared with the Commission and Professional Team. All data files, data sets, and source code are stored in centralized repositories to ensure KCC staff have access to the latest information and can verify all changes. All changes are first discussed in meetings between Subject Matter Experts (SMEs) and documents are updated upon approval. As changes are implemented, documented checklists are followed to ensure agreement and correctness between databases, data files, and source code to presentation materials, technical papers, and KCC modeling documents.

Standard Verified

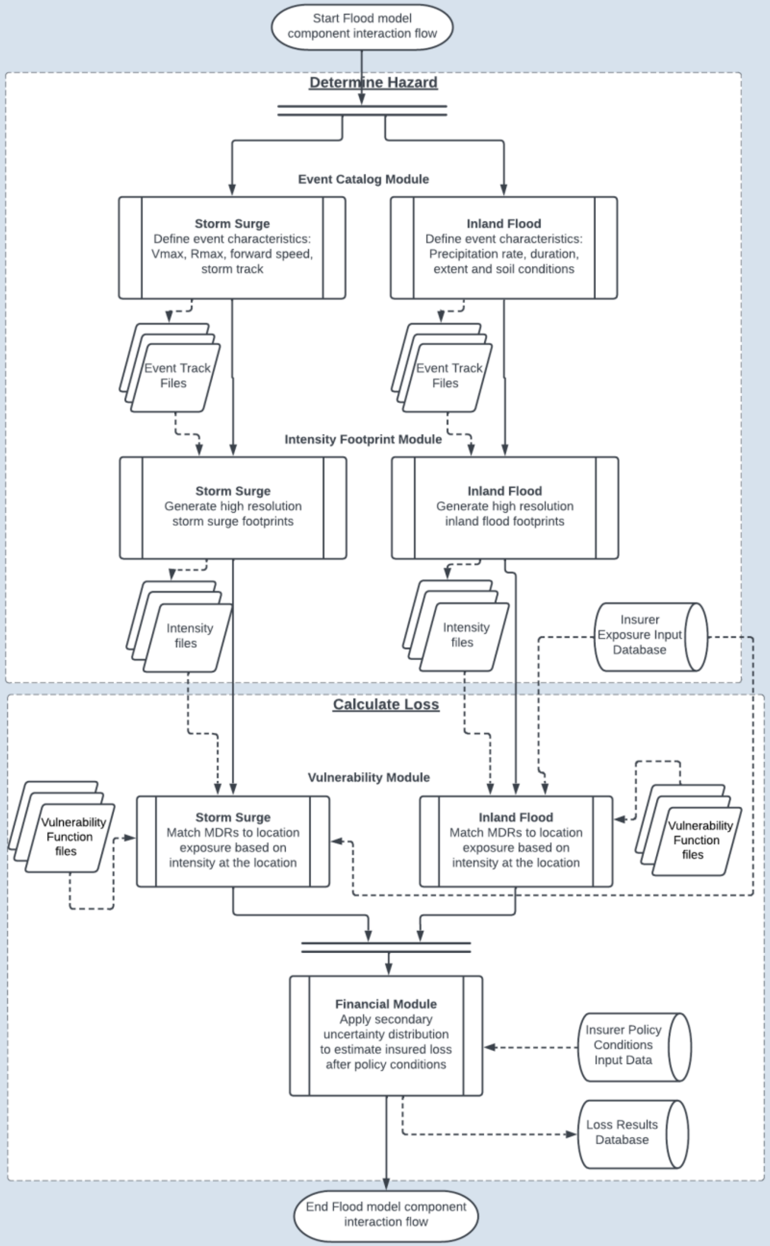


Figure 3 - Flowchart of major model components in the KCC US Flood Reference Model

KCC Meets Standard GF-1: Scope of the Flood Model and Its Implementation

- All information and software files used to develop and validate the model and generate losses for the KCC US Flood Reference Model are centrally located and comply with the Computer/Information Standards. As specified in the Computer/Information Standards, KCC uses Microsoft Team Foundation Server and Github to maintain all source code, data files, flowcharts, and documentation pertaining to the KCC US Flood Reference Model. This includes all materials used to generate the KCC submission document and associated forms.

- Considering the available flood loss data, the differences between historical and modeled flood losses are reasonable. Some differences are to be expected due to inconsistent reporting of flood losses, changes to exposure, and the reliability of historical flood data.

- The vintage of data, code, and scientific and technical literature used to develop and validate the KCC US Flood Reference Model has been justified by the appropriate SMEs

Standard Verified

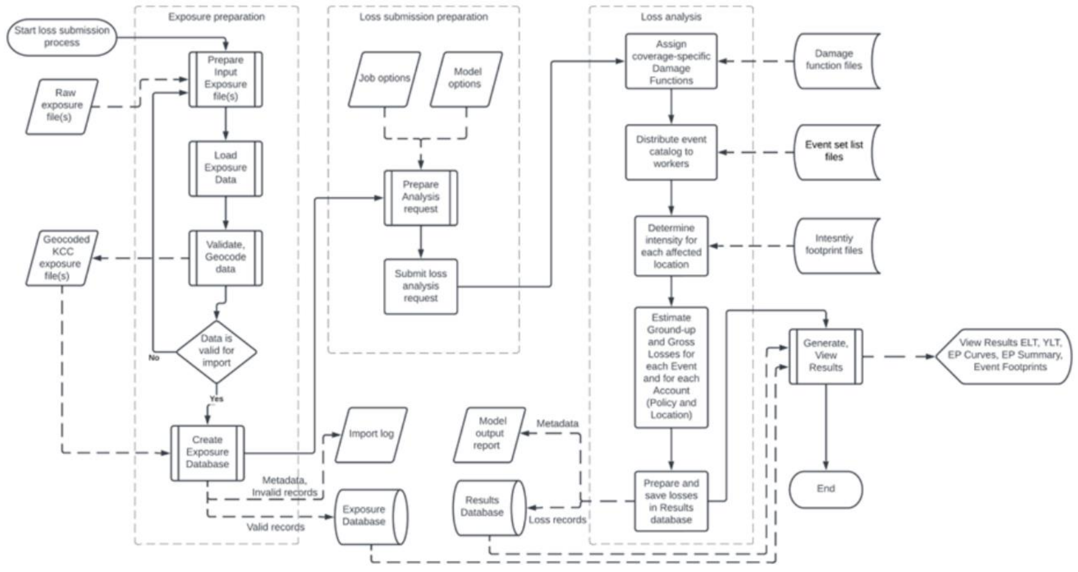


Figure 55 - Sample flowchart employed in KCC documentation standards

KCC Meets Standard GF-2: Qualifications of Modeling Organization Personnel and Consultants Engaged in Development of the Flood Model

- The KCC US Flood Reference Model was developed and verified by professionals who possess the requisite experience and formal education. Further information about the qualifications of individuals involved in the development, testing, and evaluation of the KCC US Flood Reference Model can be found in Standard GF-2, Disclosure 2A.

  KCC professionals possess a wide range of skills and expertise in fields including meteorology, hydrology, hydraulics, engineering, computer science, and statistics honed through experience and education. All model developers possess advanced degrees, and the majority hold PhDs in their fields. At each stage of model development, these experts evaluated and tested the model for accuracy and reliability using accepted methodologies and rigorous standards appropriate to their respective disciplines.

- The KCC US Flood Reference Model and associated documentation have been thoroughly reviewed by individuals holding the above-mentioned qualifications.

Table 2 - Credentials and tenure of individuals contributing to the KCC US Flood Reference Model

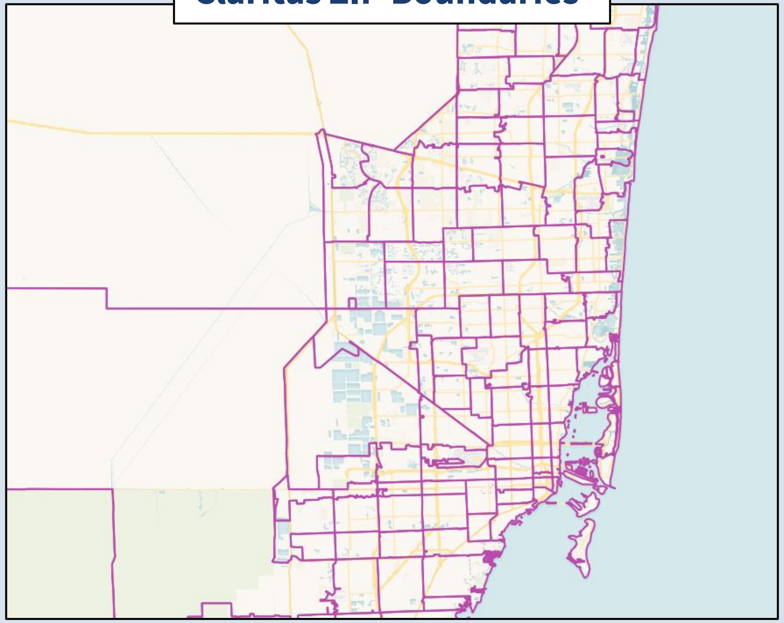
Standard(s)	Individual	A. Degree, Discipline, University	B. KCC Status / Tenure (years)	C. Experience and Responsibilities
Computer/ Information	Adrian Corman	Ph.D., Physics, University of Missouri	Principal Software Developer / 4	Dr. Corman has more than ten years of professional programming experience and a strong analytical background. Prior to joining KCC, Dr. Corman was a programmer analyst where he streamlined company processes, maintained SQL databases, created backend and frontend software, and developed stored procedures to increase efficiency. During his graduate research, he used advanced statistical techniques to identify correlations in data and developed software to convert raw data into an appropriate input for computer simulations. His contributions to the KCC US Flood Reference Model include work on the footprint generation module, such as coding the algorithm used for riverine flooding.
Vulnerability	Arjun Jayaprakash	Ph.D., Civil Engineering, North Carolina State University	Principal Engineer / 3	Since joining KCC, Dr. Jayaprakash has contributed to the development of the KCC industry property database (KPD) as well as the vulnerability modules and model validation for several earthquake and hurricane models, including the KCC Central America Earthquake, Mexico Earthquake, and US Hurricane Reference Models.
Computer/ Information	Arthur Phung	B.S., Mechanical Engineering, Boston University	Senior Software Developer / 2	Mr. Phung contributes to RiskInsight® software development and has worked on a modern, web-based user interface for submitting losses and an integrated licensing system to verify valid hardware clients connected to the platform. Mr. Phung is also responsible for implementing
*	*	*	*	*
*	*	*	*	*
*	*	*	*	*

Standard Verified

KCC Meets Standard GF-3: Insured Exposure Location

- KCC uses United States Postal Service (USPS) ZIP Code data that is post-processed by a third-party vendor, Claritas. The current KCC ZIP Code database is from October 2022.
- Florida Department of Revenue's Tax data Parcel database (2020) is used for the horizontal location information. KCC's ZIP Code centroid data is obtained from Claritas's "ZIPCENT22" dataset, and 2020 US Census population data. The centroids are population-weighted and examined to ensure accuracy and that centroids are also constrained to be within the boundary of the respective ZIP Code. KCC confirms that these conditions are met through visual verification.

Claritas ZIP Boundaries



Standard Verified

KCC Meets Standard GF-3: Insured Exposure Location

- Spatial information on the local municipality boundaries and other information about Flood Insurance Rate Map (FIRM) dates and Flood Zones are used in the model vulnerability component and derived from the National Flood Hazard Layer (NFHL) database. KCC maintains a logical process for ensuring consistency and for updating these databases.
- The KCC geocoding methodology uses justified, industry-proven geocoding methods that are routinely quality-checked to ensure accuracy.
- In the KCC US Flood Reference Model, the horizontal datum reference is World Geodetic System 1984 (WGS84), and the vertical datum reference is the North American Vertical Datum of 1988 (NAVD1988). The vertical datum of National Geodetic Vertical Datum of 1929 (NGVD29) related to the water surface elevation from USGS gauge data is converted to North American Vertical Datum of 1988 (NAVD88), which is consistent with the vertical datum of the Digital Elevation Model data from USGS.

Sample of Exposure Points for a Florida Location

Standard Verified

KCC Meets Standard GF-4: Independence of Flood Model Components

- As a part of the model development process, each component is independently validated to ensure that no components are biased. These validations are completed using external data with as many different perspectives as feasible to ensure the consistency and validity of validation results. If a component does not pass a validation test, the component is re-evaluated by KCC scientists, engineers, and/or actuaries to ensure the correctness and accuracy of the component.

  Additionally, components are analyzed during the model development process to ensure that a logical relationship to risk is held throughout the entire model. These analyses include visual inspection of event footprints against location-level loss costs to verify that higher inundation levels exhibit higher losses and examining losses by building type or secondary modifier to ensure the appropriate building types consistently sustain losses appropriate to their expected vulnerability.

  Using these methods, the KCC US Flood Reference Model is theoretically sound and has no compensation for potential bias within any component of the model.

Standard Verified

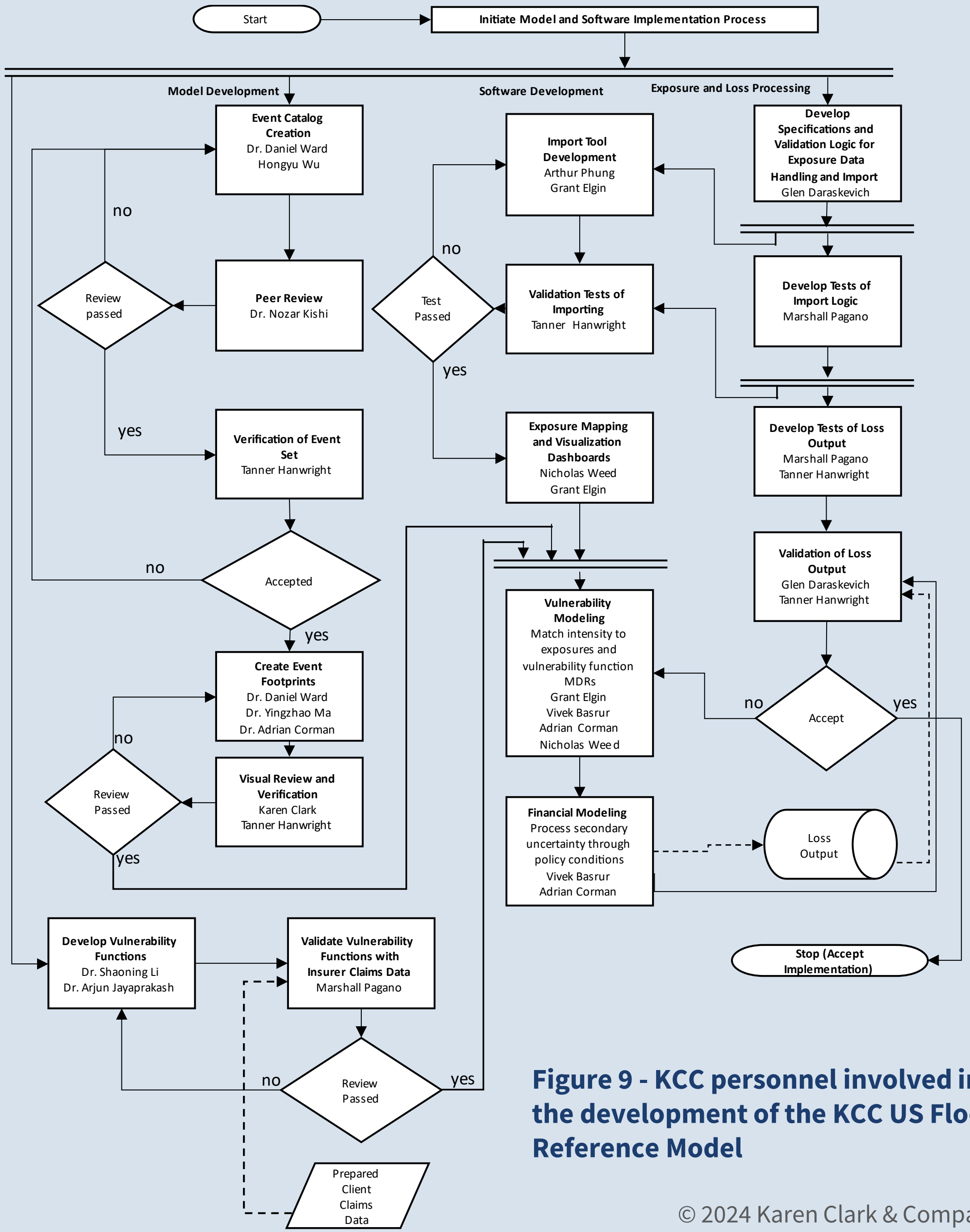


Figure 9 - KCC personnel involved in the development of the KCC US Flood Reference Model

KCC Meets Standard GF-5: Editorial Compliance

- The flood model submission and revisions have been reviewed and edited by a person with the requisite experience. In signing Form GF-8, Editorial Review Expert Certification, the signatory certifies that the submission document has been personally reviewed and is editorially correct.

Standard Verified

KCC Meets Standard MF-1: Flood Event Data Sources

- The KCC US Flood Reference Model is based on technical literature and data sources encompassing meteorological, hydrological, hydraulic, and other relevant data sources required to model coastal and inland flooding.
- The KCC US Flood Reference Model incorporates data sources accounting for meteorological, hydrological, and hydraulic events and circumstances occurring inside or outside Florida that result in or contribute to flooding in Florida.

Data Source	Release Date	Time Period
Climate Prediction Center Unified Gauge-Based Analysis of Precipitation	2/28/2022	01/01/1948-12/31/2021
Global Peak Storm Surge Database (SURGEDAT); Needham and Keim (2013)	2/1/2015	1/1/1880-2/1/2015
National Hurricane Center Tropical Cyclone Reports	4/7/2017-3/17/2023	2/1/2015-12/31/2022
HURDAT2 (Landsea and Franklin, 2013)	4/19/2022	1/1/1900-12/31/2021

Table 3 - Sources, release dates, and included time periods of data used to develop the KCC US Flood Reference Model

Standard Verified

KCC Meets Standard MF-1: Flood Event Data Sources

- Coastal and inland flood model calibration and validation are justified and based on historical data consistent with peer reviewed or publicly developed data sources.
- The KCC US Flood Reference Model was developed with no weighting or partitioning of historical data. Historical hurricane intensity data are trended to account for the effects of climate change for the purpose of fitting the model intensity distributions.

Standard Verified

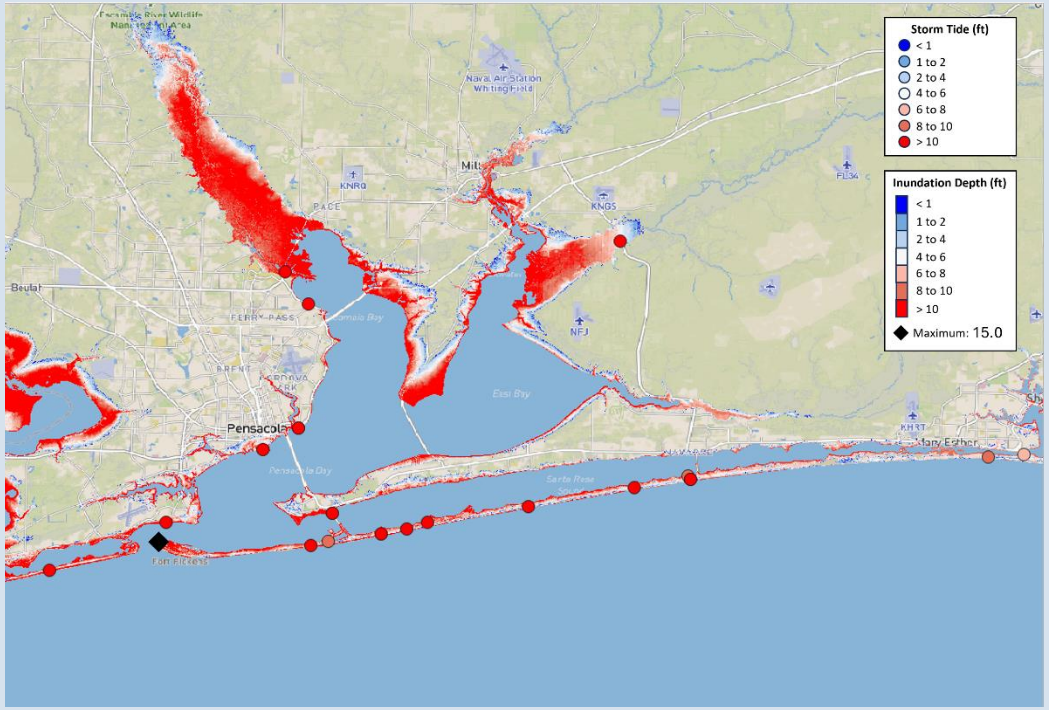
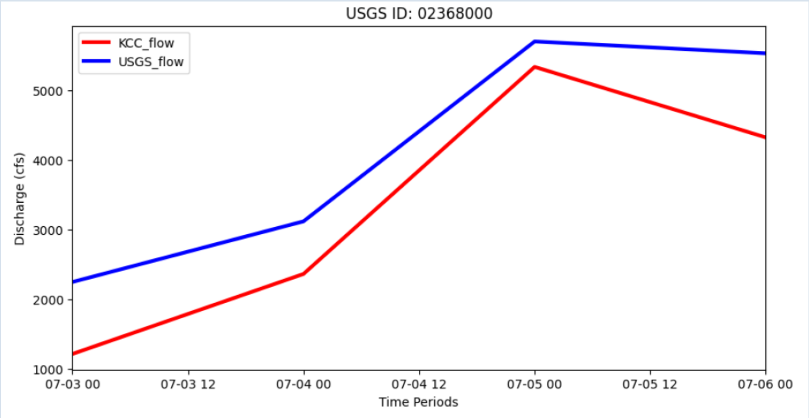


Figure 58 - Hurricane Ivan (2004) Coastal Flood Footprint

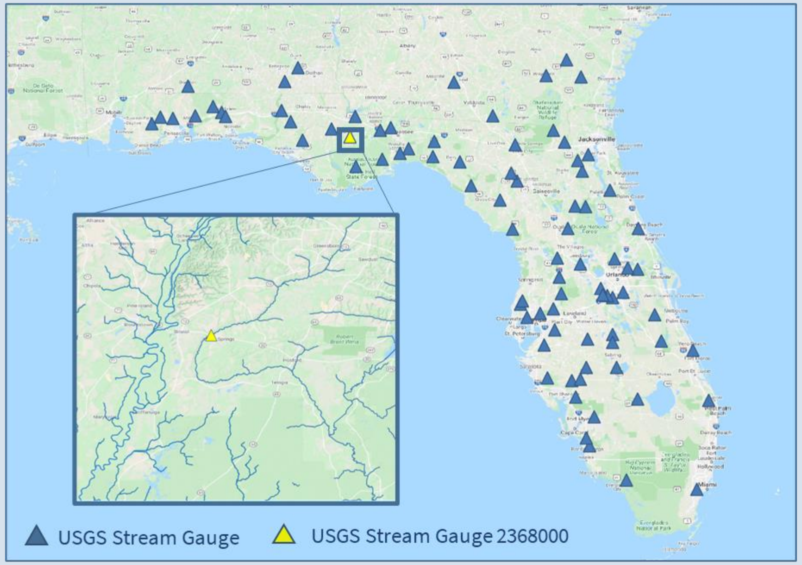
KCC Meets Standard MF-1: Flood Event Data Sources

- Coastal and inland flood model calibration and validation are justified and based on historical data consistent with peer reviewed or publicly developed data sources.
- The KCC US Flood Reference Model was developed with no weighting or partitioning of historical data. Historical hurricane intensity data are trended to account for the effects of climate change for the purpose of fitting the model intensity distributions.

Standard Verified



From Figure 31 - River Discharge for the July 2013 flood event



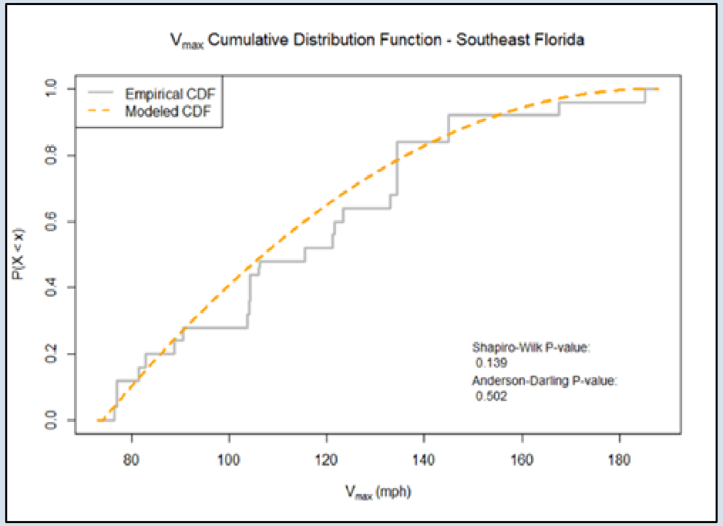
Locations of USGS Stream Gauges

KCC Meets Standard MF-2: Flood Parameters (Inputs)

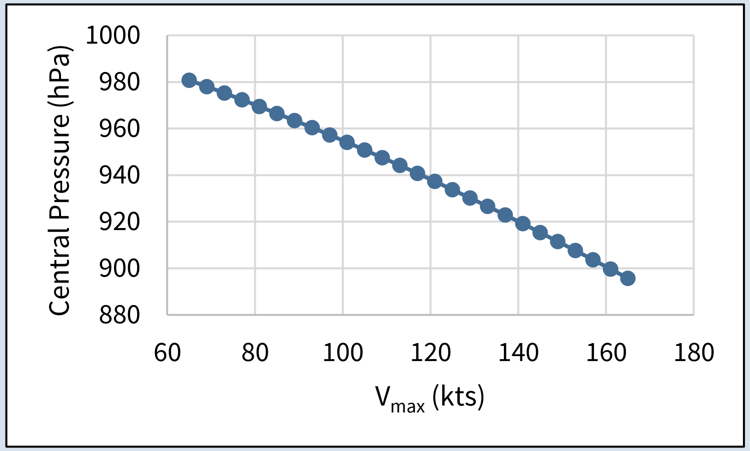
- Scientifically appropriate flood parameters were used when developing the KCC US Flood Reference Model, and the selection of parameters was based on current scientific and technical literature. Additional information on the justification of parameters is found in Standard MF-2, Disclosure 1.

- There are no differences in the treatment of flood parameters between historical and stochastic events in the KCC US Flood Reference Model.

Historical and Model Fit V_{max}



Relationship between V_{max} and Central Pressure

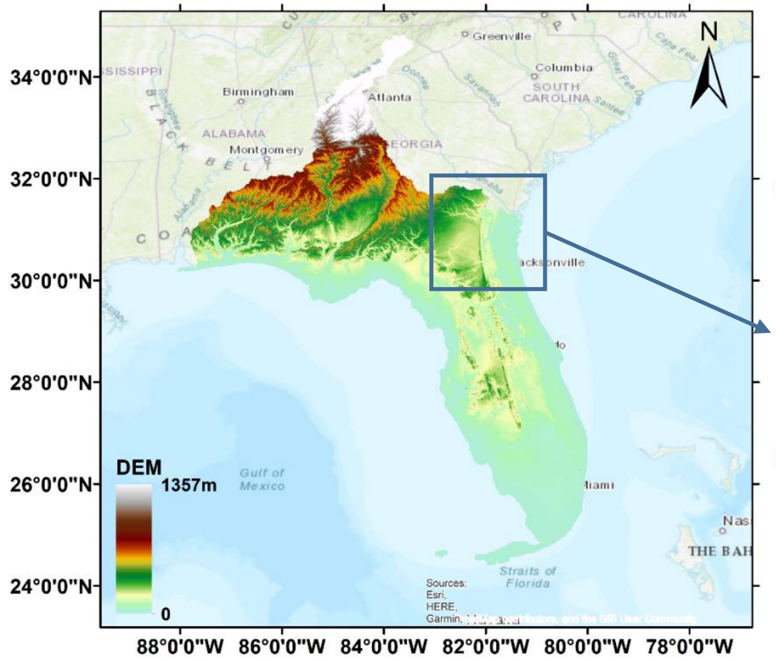


Standard Verified

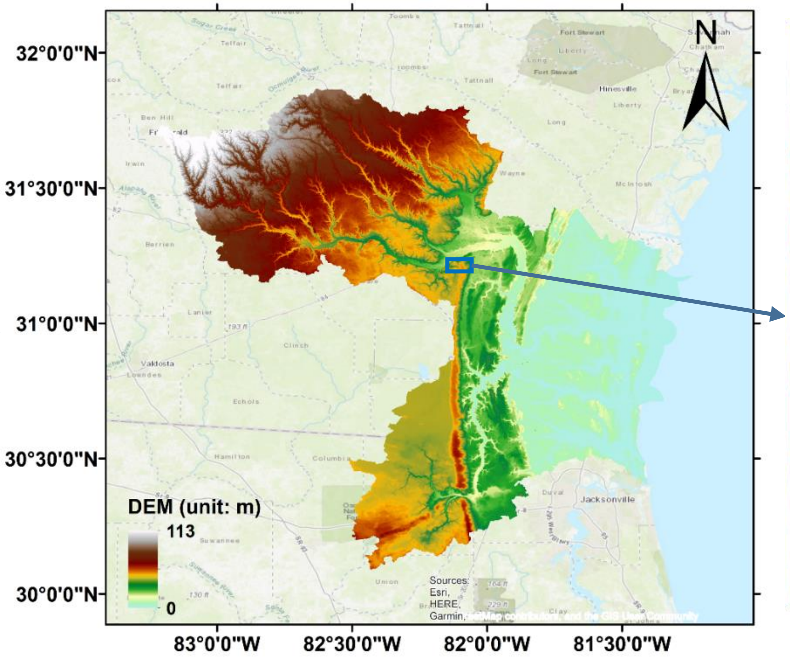
KCC Meets Standard MF-2: Flood Parameters (Inputs)

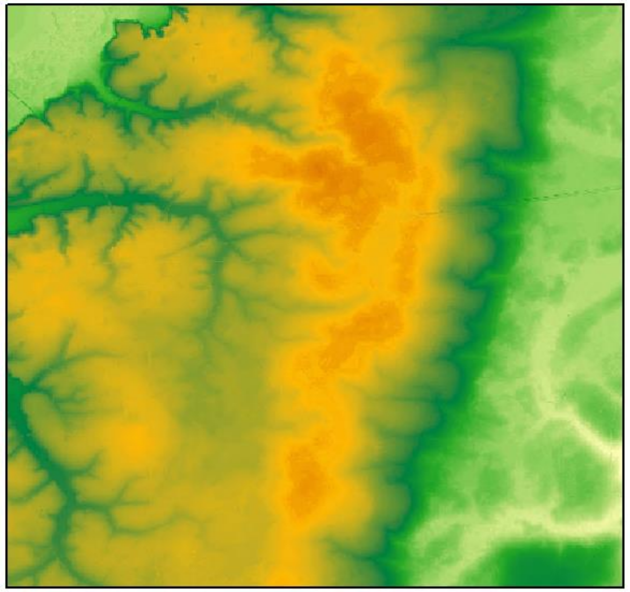
- The KCC US Flood Reference Model employs a grid size of 1 arc-second. This grid size was selected based on comparisons of different grid sizes to the average building size and the scale of elevation changes. From these analyses results, KCC scientists concluded that the grid size of 1 arc-second produced the most accurate results for calculating location-level inundation.

DEM in Florida



DEM in St. Mary's



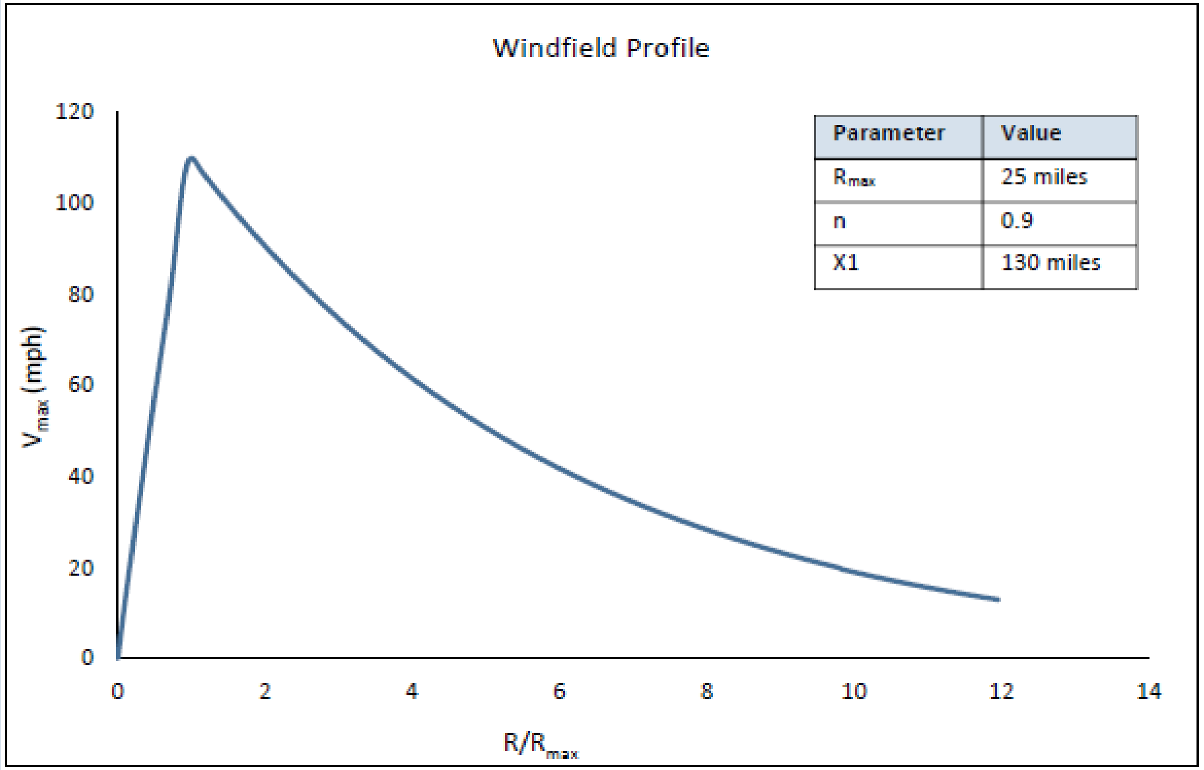


Standard Verified

KCC Meets Standard MF-3: Wind and Pressure Fields for Storm Surge

- The KCC US Flood Reference Model uses the radius of maximum winds (R_{max}) and central pressure (CP), which are both calculated based on the maximum wind speed, to drive storm surge from tropical cyclones.

- The development of the wind fields is based on the Willoughby et al. (2006) radial wind model, and central pressure is calculated using the work of Courtney and Knaff (2009).

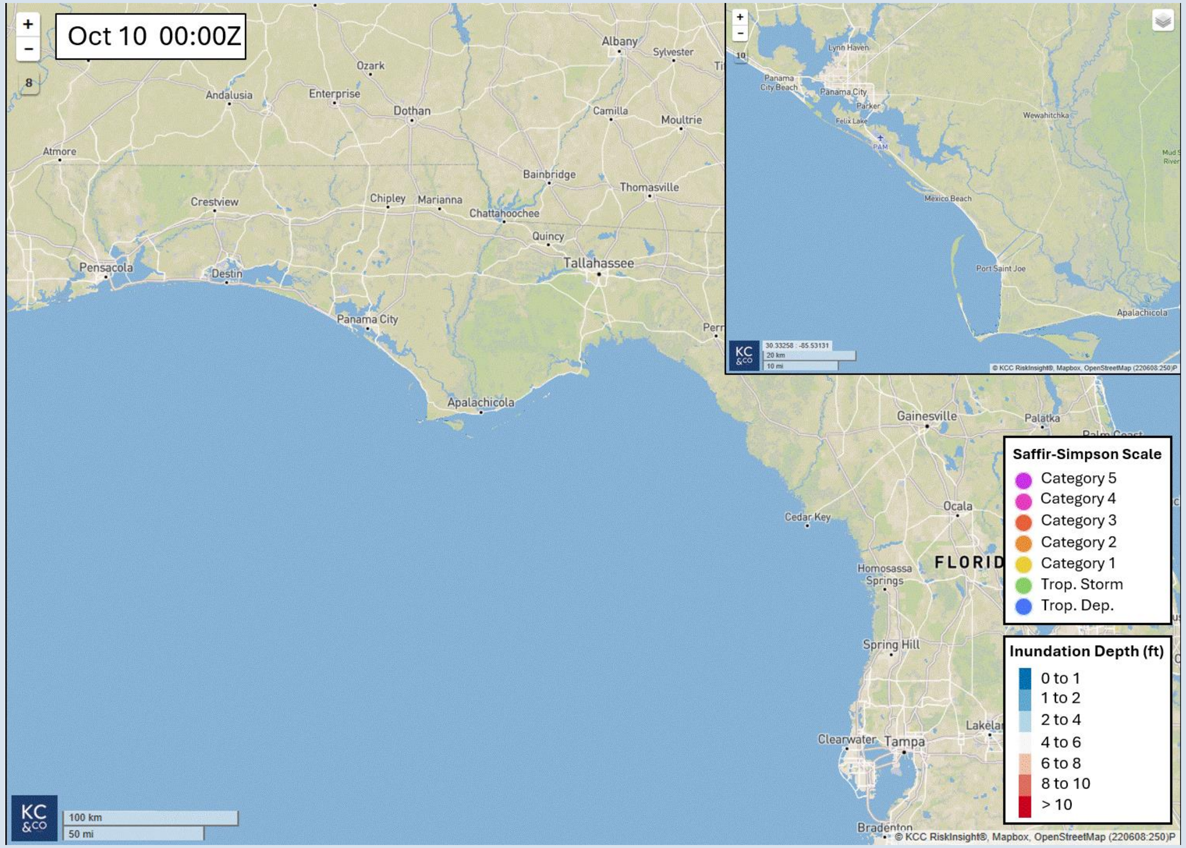


Standard Verified

KCC Meets Standard MF-3: Wind and Pressure Fields for Storm Surge

- The storm surge is calculated for the entire US coast at each 5-minute time step of the modeled events.
- The features of modeled wind and pressure fields are consistent with those of storms historically affecting Florida. The KCC US Hurricane Reference Model wind footprints have been validated against observed wind speeds tabulated by the NHC, and those events form the basis of the KCC US Coastal Flood Reference Model.

Animation of Overland Coastal Surge Estimates



Standard Verified

KCC Meets Standard MF-4: Flood Characteristics (Outputs)

- The flood extent and depth generated by the flood model have been validated using observations from historical coastal and inland flood events.
- The flood extent and inundation depth are simulated using technically sound methods that make use of published scientific literature.

Standard Verified

Figure 57 - Hurricane Andrew (1992) Coastal Flood Footprint

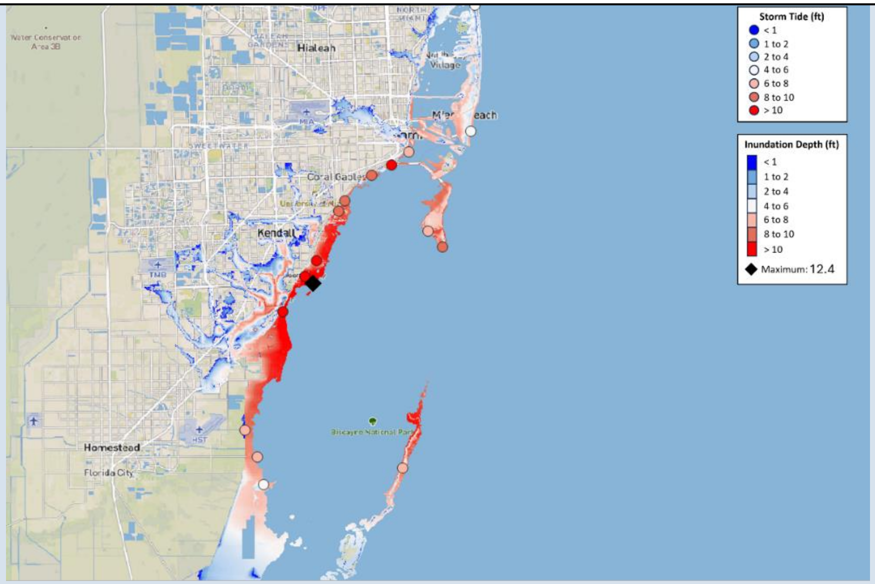
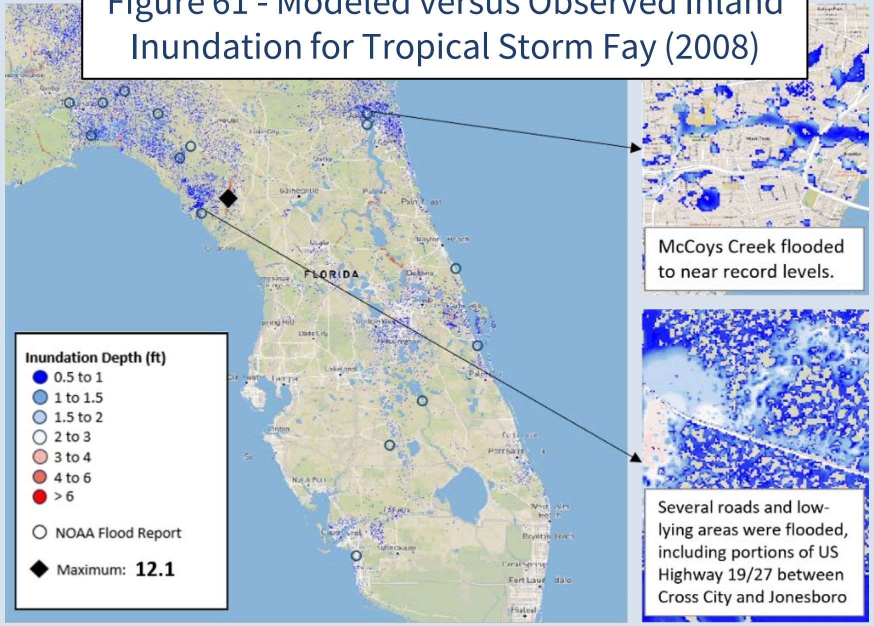


Figure 61 - Modeled versus Observed Inland Inundation for Tropical Storm Fay (2008)

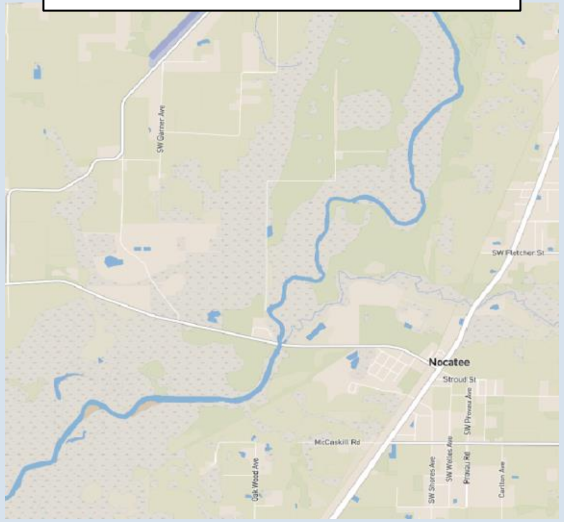


KCC Meets Standard MF-4: Flood Characteristics (Outputs)

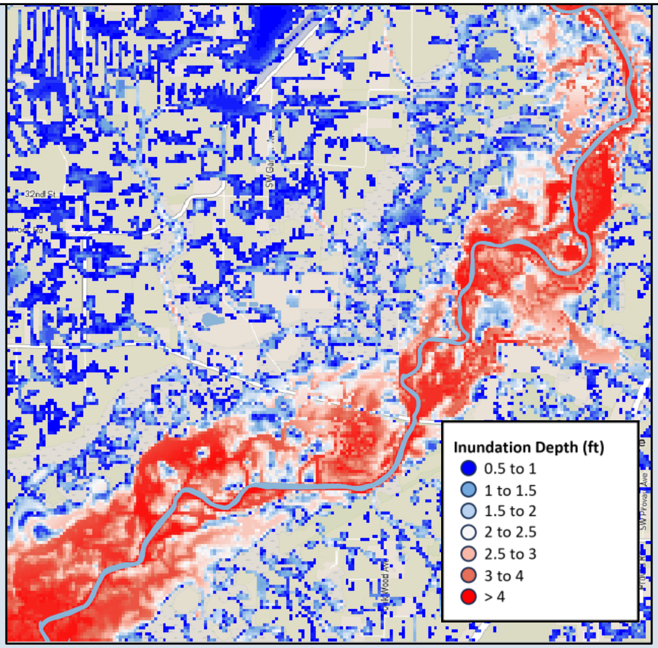
- The KCC US Flood Reference Model implicitly addresses the wave impact on the flood elevations in the vulnerability functions. For this purpose, the wave height is assumed to be a function of the inundation depth (FEMA, 2011).
- The flood model simulates all flood characteristics required for calculating flood damage including maximum inundation depth and flood spatial extent.

Standard Verified

Section of the Peace River



Flooding Along the Peace River during Irma (2017)



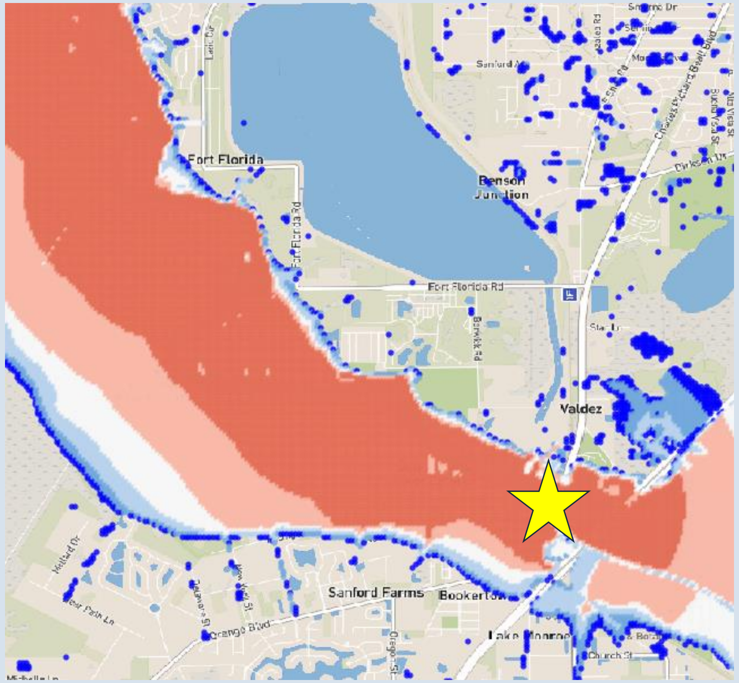
KCC Meets Standard MF-5: Flood Probability Distributions

- Flood probability, flood extent, and inundation depth are validated with observations of historical floods in the state of Florida.

- Flood probability distributions for coastal areas include storm surge driven by tropical cyclones affecting Florida.

Standard Verified

KCC 50-year Return Period Flood Map Near Sanford (Seminole County)



Water surface elevation above mean flow

Statistic	Inundation Depth
Model 50-year	8.67 ft
Historical Max	6.90 ft
Model 10-year	6.25 ft

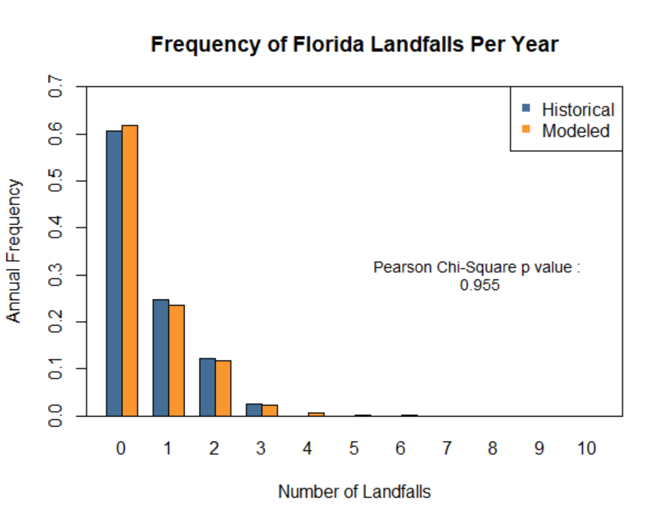
KCC Meets Standard MF-5: Flood Probability Distributions

- The KCC US Flood Reference Model implicitly addresses the wave impact on the flood elevations in the vulnerability functions. For this purpose, the wave height is assumed to be a function of the inundation depth, and the added forces due to waves are accounted for when assessing building vulnerability. The relationship between wave height and inundation in the KCC US Flood Reference Model is based on recent publications as described in the Vulnerability Standard disclosures.

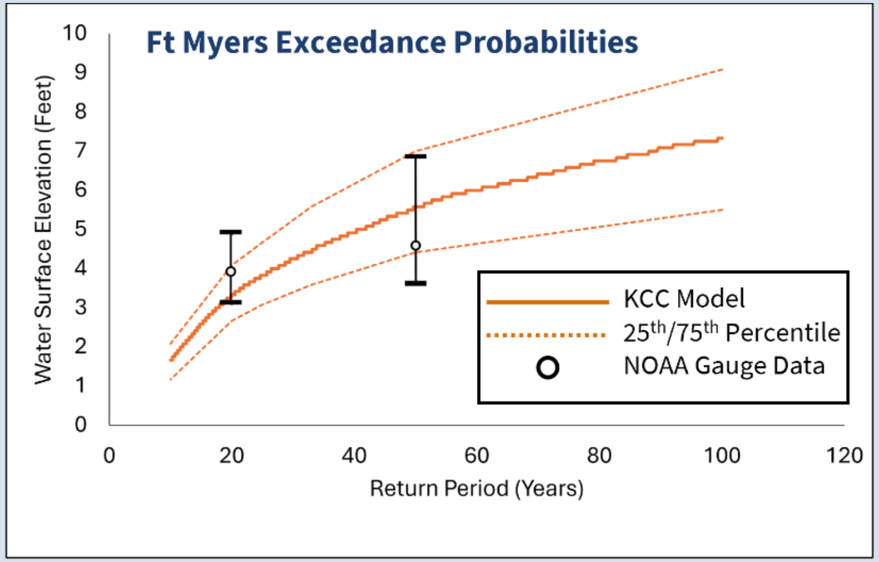
- The probability distributions of all flood parameters and modeled characteristics are derived from historical coastal flooding events in Florida and historical extreme precipitation events that are consistent with historical datasets.

Standard Verified

Florida Hurricane Landfall Frequency



Adapted from Figure 16 – Sample water elevation validation with NOAA tide gauge data

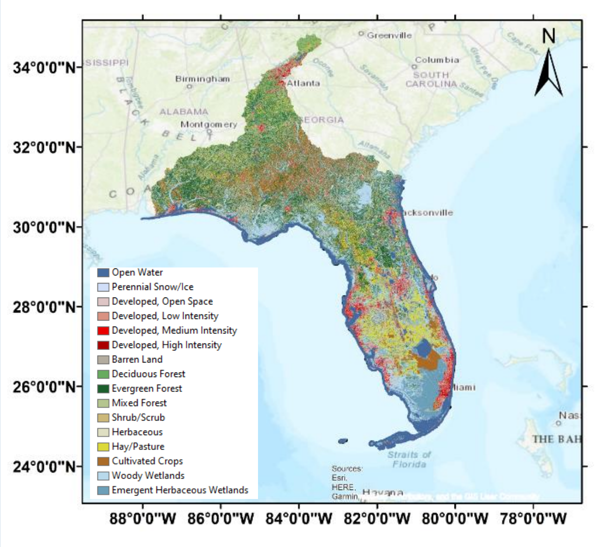


KCC Meets Standard HHF-1: Flood Parameters (Inputs)

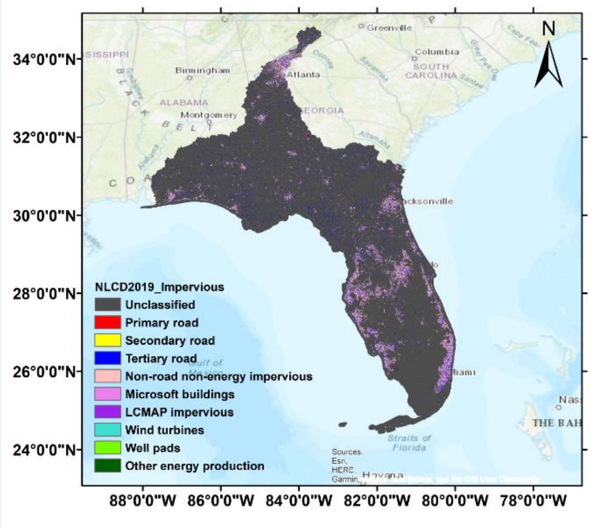
- KCC employs the 2019 NLCD LULC database for land use/land cover information. The treatment of LULC is consistent with current scientific and technical literature.

Standard Verified

Map of the NLCD (2019) Land Cover Types



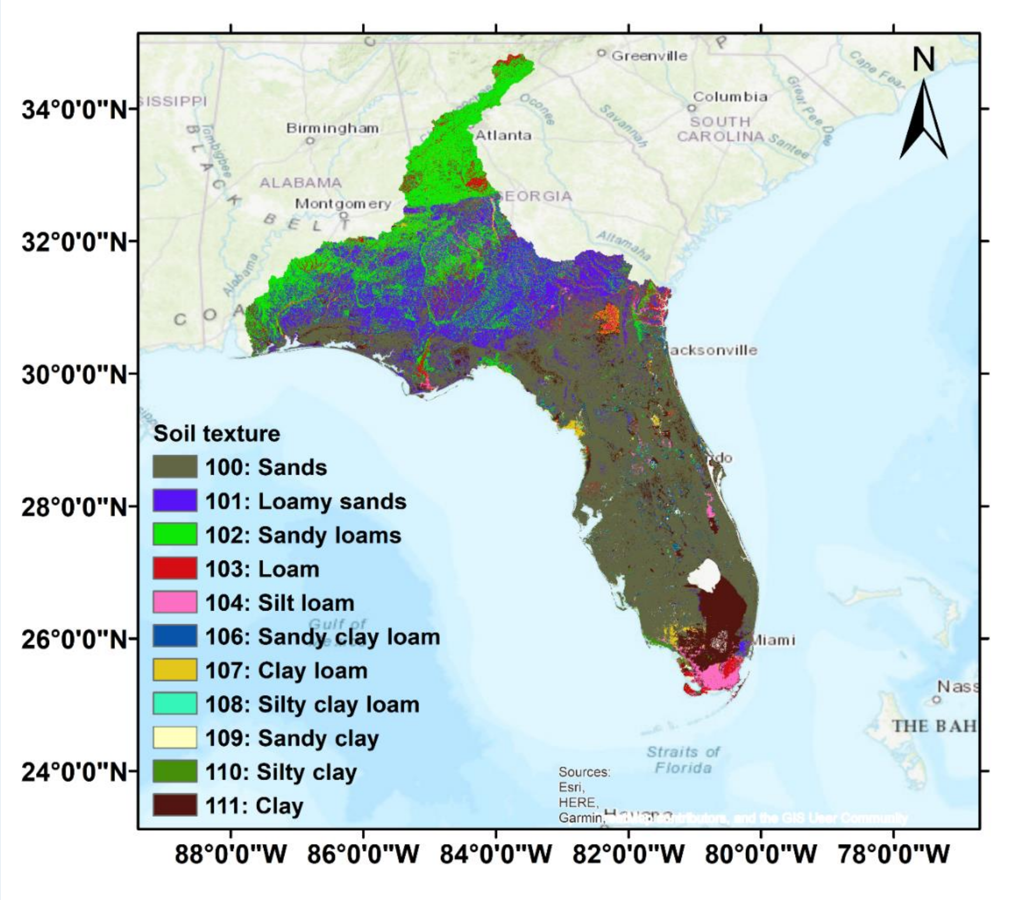
Map of the NLCD (2019) Impervious Data



KCC Meets Standard HHF-1: Flood Parameters (Inputs)

- The treatment of soil effects on inland flooding in the KCC US Flood Reference Model is consistent with current scientific and technical literature. A full list of scientific and technical literature used in the development of the model has been provided.

Spatial Distribution of Soil Texture



Standard Verified

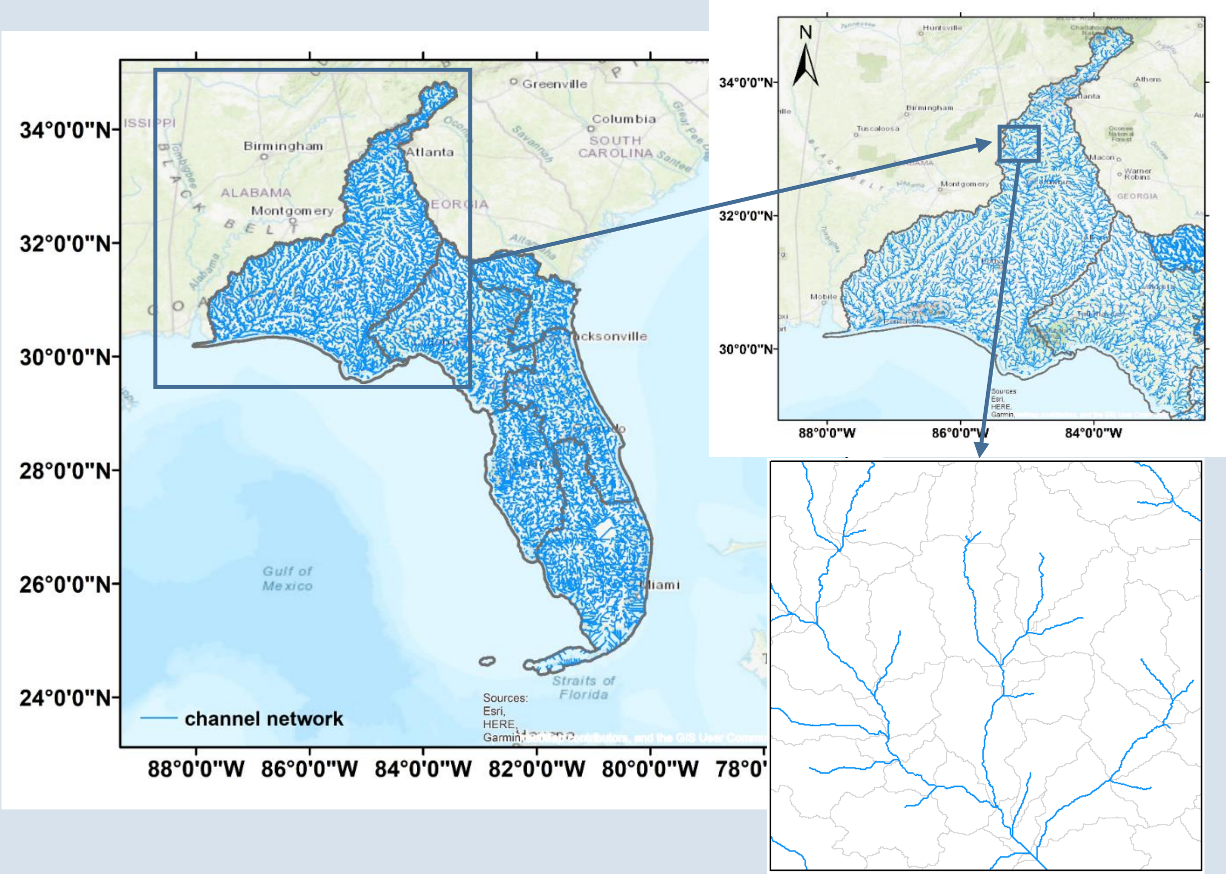
KCC Meets Standard HHF-1: Flood Parameters (Inputs)

- The treatment of watersheds and hydrologic basins in the KCC US Flood Reference Model is consistent with current scientific and technical literature. A full list of scientific and technical literature used in the development of the model has been provided.

- The treatment of hydraulic systems, including conveyance, storage, and hydraulic structures in the KCC US Flood Reference Model are consistent with current scientific and technical literature. A full list of scientific and technical literature used in the development of the model has been provided.

Standard Verified

KCC Flood Model Hydraulic Network

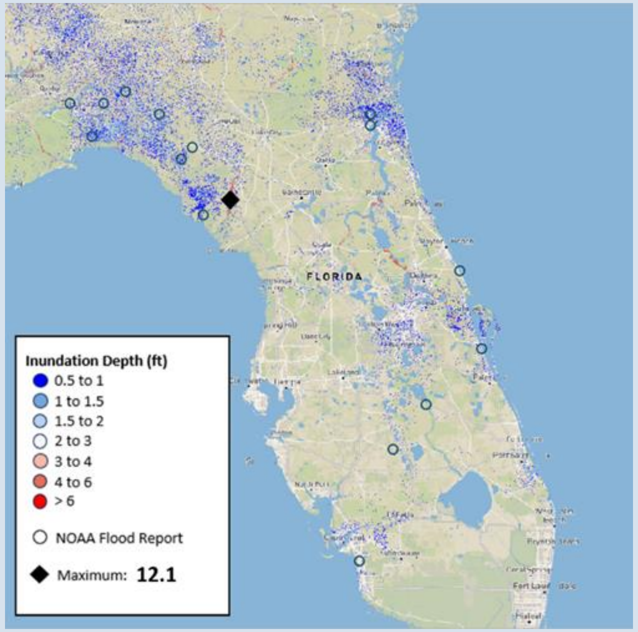


KCC Meets Standard HHF-2: Flood Characteristics (Outputs)

- Flood extent and depth generated by the KCC US Flood Reference Model are consistent with observed historical floods affecting Florida. Additional validation can be found in Standard HHF-2, Disclosure 1.

- The KCC US Flood Reference Model exports the maximum flood depth for a certain location during the event. Analysis of inundation versus flood velocity for surface runoff and channel flows showed that the maximum depth per second is a reasonable estimate for inland flood velocity. This is consistent with FEMA (2011) lower bounds of flood velocity for storm surge. The calculation of flood damage is generated using these modeled flood characteristics.

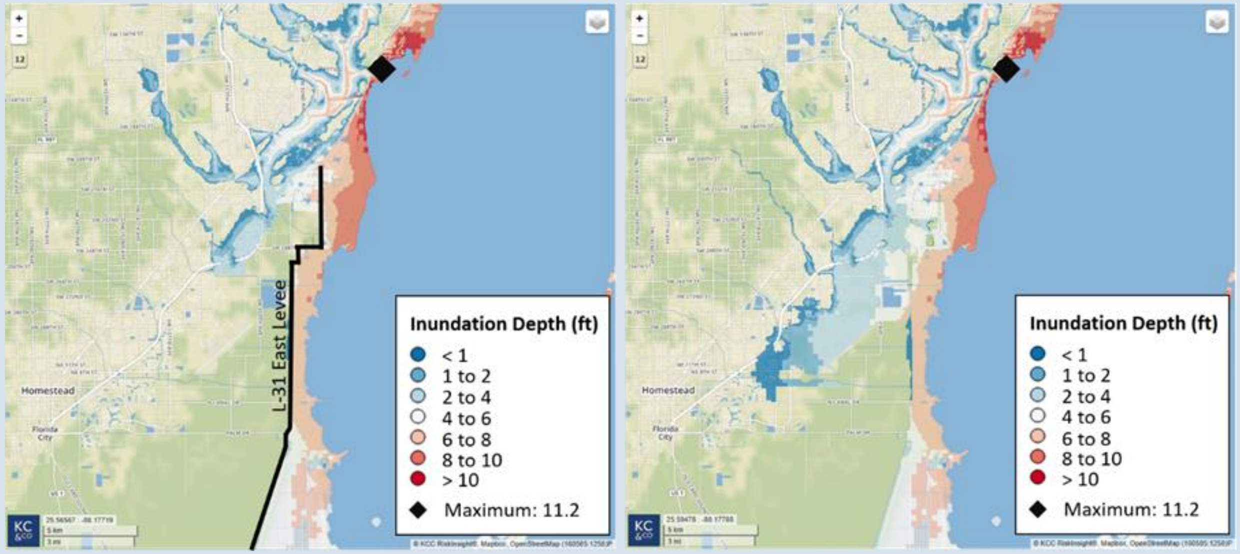
Figure 22 - Comparison of NOAA reports of flood depth to KCC inland flood intensity footprint for Tropical Storm Fay (August 2008) showing inundation depth above ground elevation from the USGS 3DEP DEM



Latitude	Longitude	NOAA flood depth, in	Modeled flood depth, in
30.6	-83.9	~ 12	12 ~ 36
30.5	-84.4	~ 12	12 ~ 36
30.5	-84.1	~ 12	12 ~ 24
30.4	-83.6	~ 12	12 ~ 36
30.4	-81.7	> 36	24 ~ 48
30.3	-81.7	> 36	12 ~ 48
30.2	-84.2	~ 12	12 ~ 36
30.1	-83.3	12 ~ 24	0 ~ 24
30.0	-83.4	12 ~ 24	6 ~ 24
29.5	-83.2	12 ~ 24	6 ~ 24
29.0	-80.9	12 ~ 24	12 ~ 24
28.3	-80.7	~ 36	12 ~ 48
27.8	-81.2	12 ~ 36	0~12
27.4	-81.5	~ 12	<12
26.4	-81.8	~ 12	< 12

Standard Verified

KCC Meets Standard HHF-3: Modeling of Major Flood Control Measures



The KCC US Coastal Flood Reference Model footprints for a major hurricane showing inundation in and around Homestead, FL (left) and with a levee break near the Black Creek Canal (right)

- Major flood control measures are consistent with state-of-the-science and available information. The KCC US Flood Reference Model includes information for major dams and levees in Florida, which is derived from the National Inventory of Dams (NID) database and National Levee Database (NLD) maintained by US USACE. Additional resources from local water management agencies are also used to supplement the USACE data. Flood control measures are modeled as height barriers along the floodplain. The USGS DEM elevation files are verified against the levee and dam data to ensure major flood control measures are included.

- KCC maintains a documented procedure for evaluating and updating information about major flood control measures. If justified, the model is updated in accordance with Standard CIF-6, Part A.

- The KCC US Flood Reference Model applies the 2D water movement method to simulate the failure of major flood control measures.

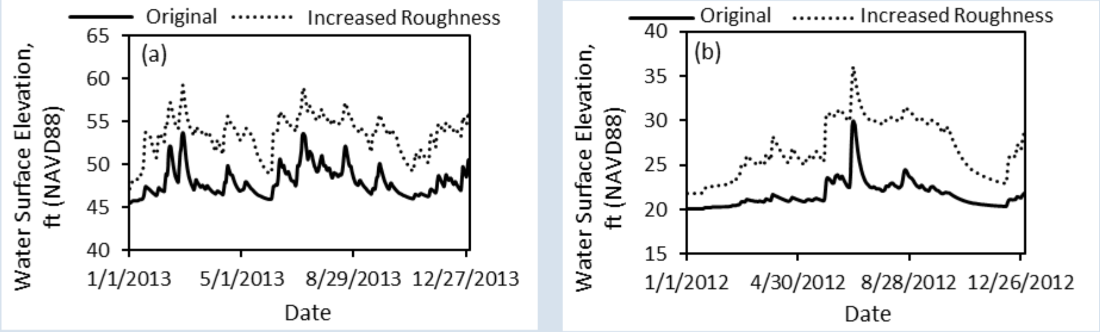
Standard Verified

KCC Meets Standard HHF-4: Logical Relationships Among Flood Parameters and Characteristics

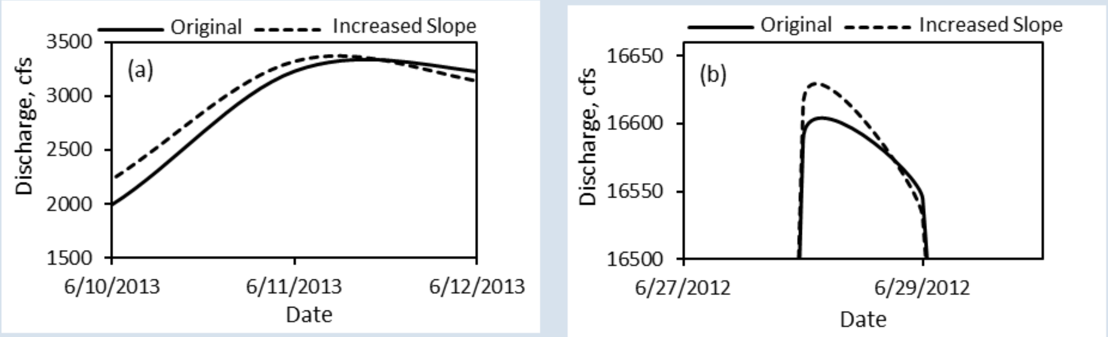
- Because Manning's equation is employed in the KCC US Flood Reference Model, as the terrain roughness increases with all other factors (terrain steepness and discharge rate) remaining constant, the cross section area will increase, which leads increased water surface elevation.
- Because Manning's equation is employed in the KCC US Flood Reference Model, as the steepness in the topography increases with all other factors (terrain roughness and cross section geometry) remaining constant, the discharge rate will increase.
- Because Manning's equation is employed in the KCC US Flood Reference Model, as the discharge rate increases with all other factors (terrain roughness and steepness in the topography) remaining constant, the cross section area will increase, which leads to increased inland flood extent and depth.

Standard Verified

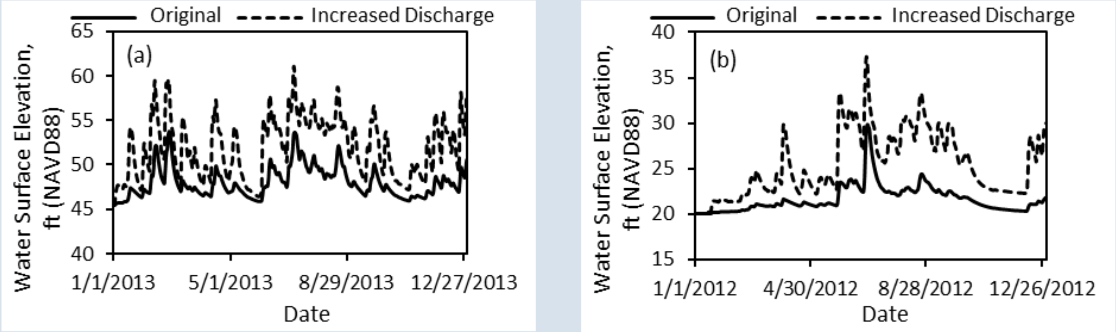
From Figure 34 - Effects of Increased Roughness on Water Surface Elevation



From Figure 35 - Effects of Increased Slope on Water Surface Elevation



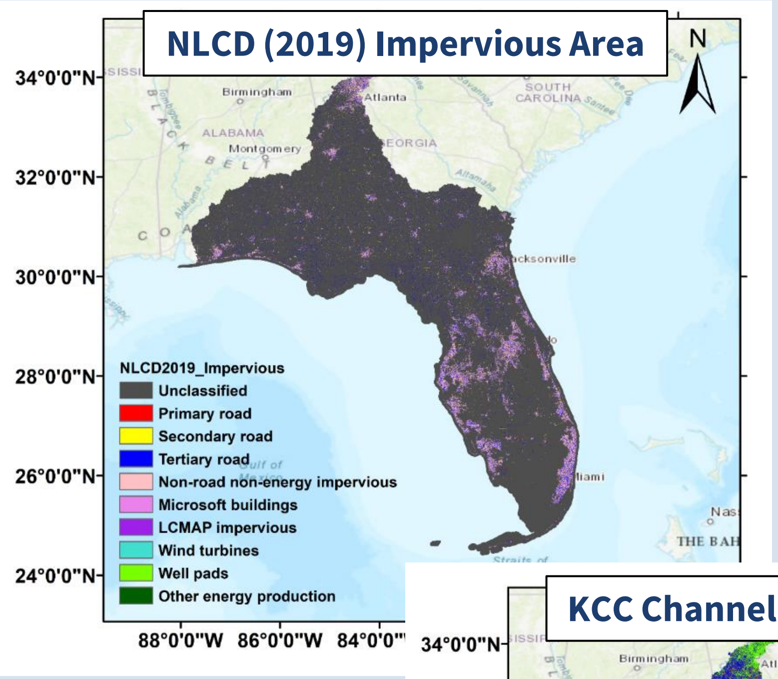
From Figure 36 - Effects of Increased Discharge on Water Surface Elevation

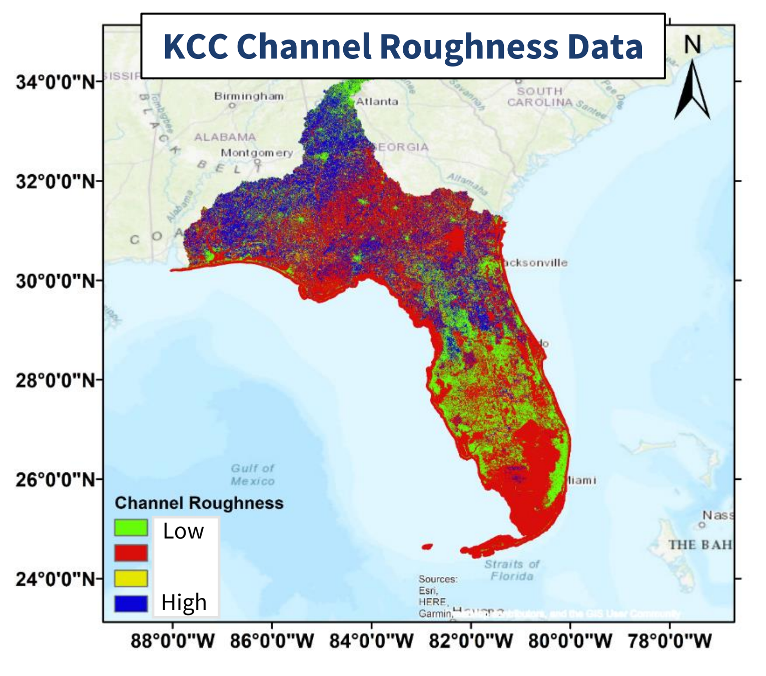


KCC Meets Standard HHF-4: Logical Relationships Among Flood Parameters and Characteristics

- In the KCC US Flood Reference Model, as the imperviousness increases with all other factors (cross section area and steepness in the topography) remaining constant, the roughness will decrease leading to an increase in the rate of discharge.

- The coincidence of storm tide and inland flooding does not decrease the flood extent and depth for either peril. The interaction between coastal and inland flooding is accounted for in the financial component of the model.





Standard Verified

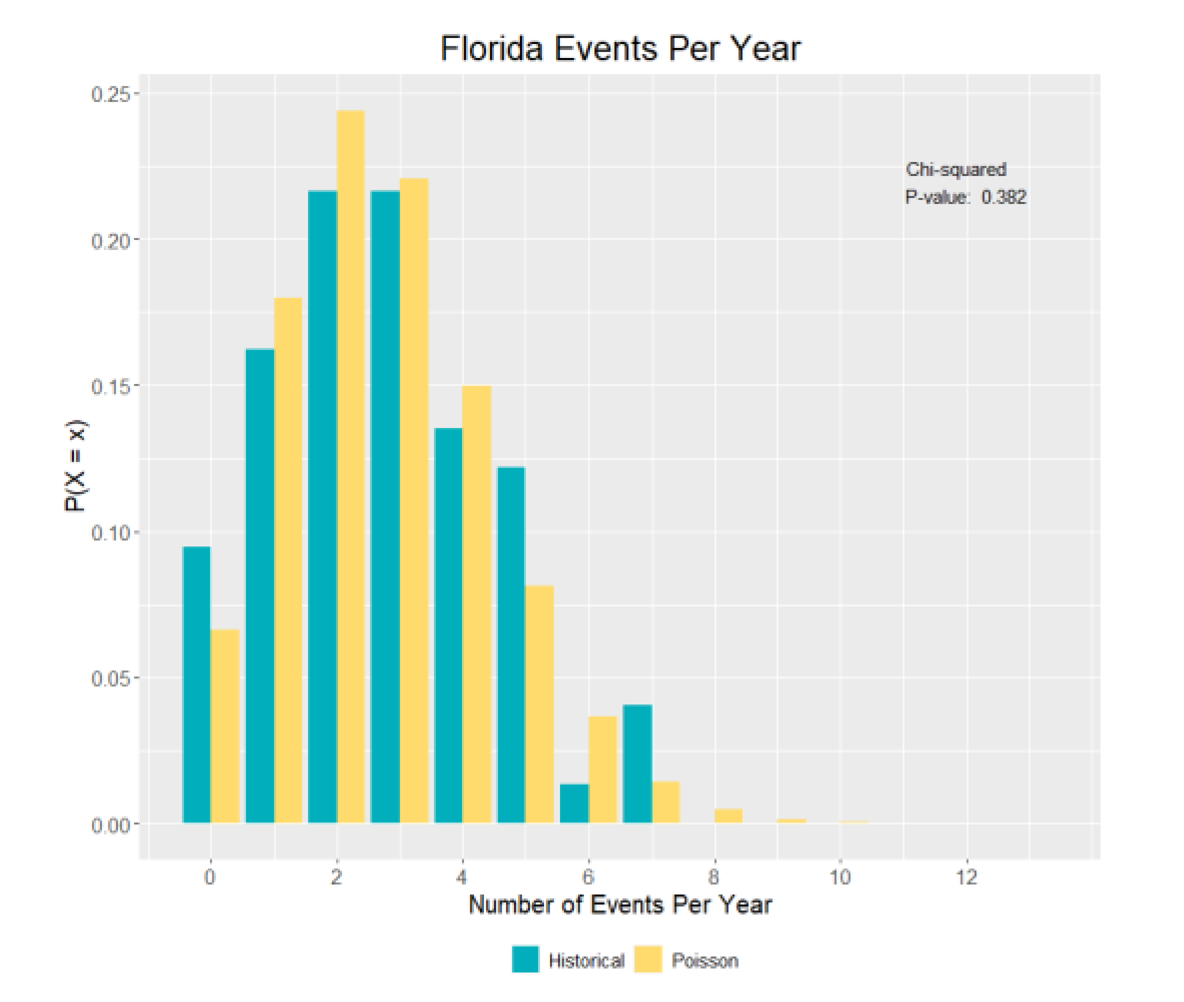
KCC Meets Standard SF-1: Modeled Results and Goodness-of-Fit

- The historical data used for the development of the coastal flood and inland flood models are from the normative data sources and are supported with rigorous data analysis techniques based on current scientific and technical literature.

- The statistical analysis of the historical data and modeled results follow statistical methods that are supported by academic literature within the appropriate disciplines.

Standard Verified

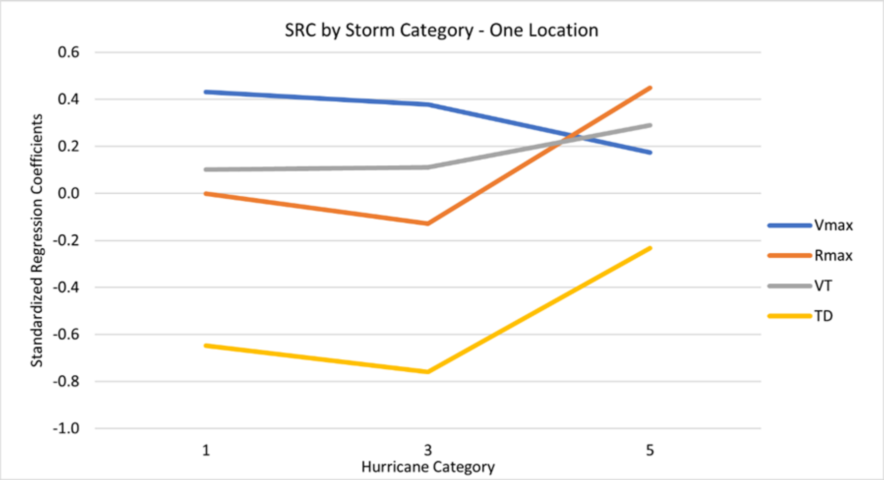
Figure 37 - Histogram of historical inland flood events per year compared to the fitted distribution used to model the number of inland flood events per year



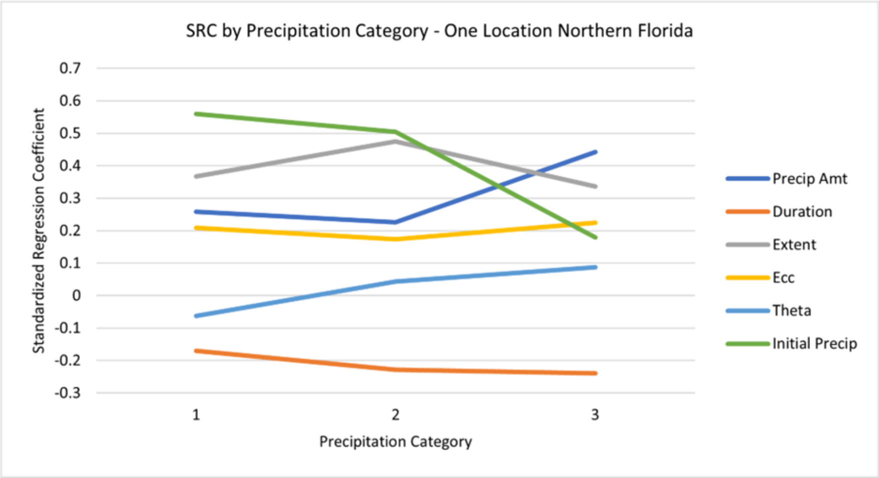
KCC Meets Standard SF-2: Sensitivity Analysis for Flood Model Output

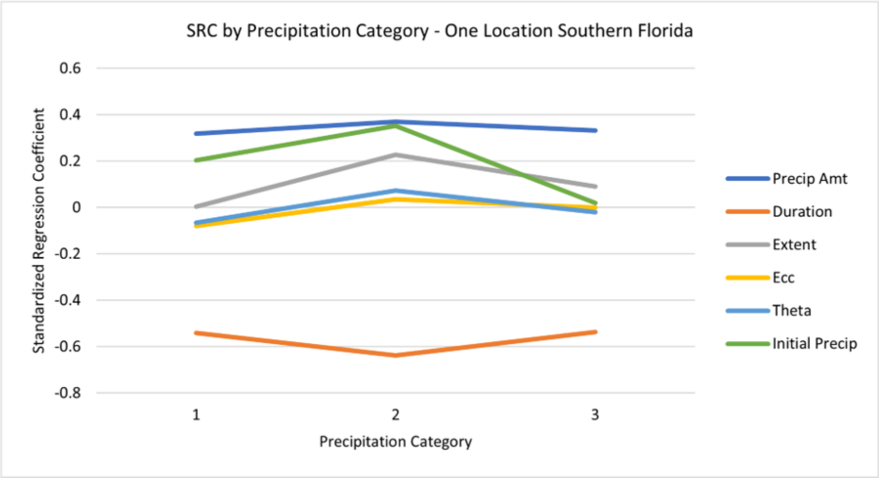
- The sensitivity of temporal and spatial outputs with respect to the simultaneous variation of input values for the KCC US Flood Reference Model has been analyzed using accepted scientific and statistical methods. Any appropriate action indicated by the results of these analyses has been taken.

SRC by storm category for coastal flooding sensitivity analysis



SRC by precipitation category for inland flooding sensitivity analysis



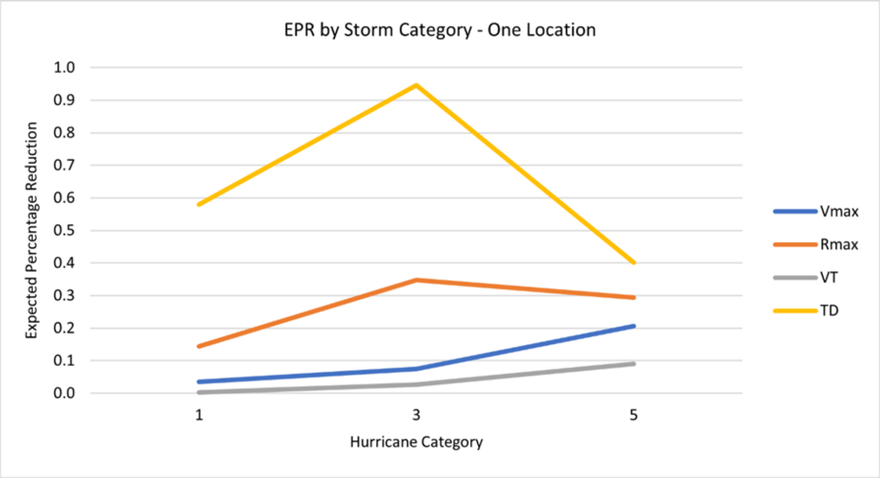


Standard Verified

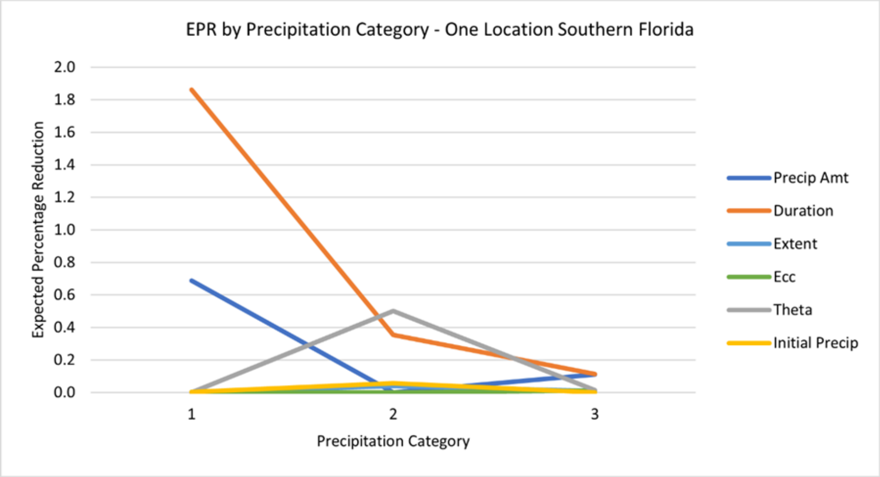
KCC Meets Standard SF-3: Uncertainty Analysis for Flood Model Output

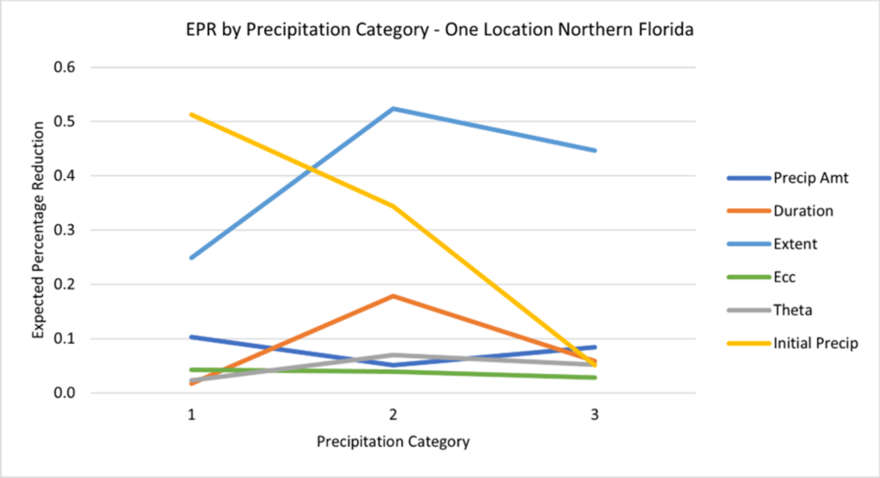
- KCC scientists and statisticians have conducted uncertainty analyses on the temporal and spatial output of the KCC US Flood Reference Model using appropriate statistical and scientific methods. The results identify and quantify the extent that input variables impact the uncertainty in flood model output. Any appropriate actions indicated by the results of the uncertainty analyses were taken.

EPR by storm category for coastal flooding uncertainty analysis



EPR by precipitation category for inland flooding uncertainty analysis





Standard Verified

KCC Meets Standard SF-4: Flood Model Loss Cost Convergence by Geographic Zone

- The KCC US Flood Reference Model attains convergence at the county level. Using 67 geographic zones (Florida counties) encompassing the entire state, the contribution of error in the flood loss costs due to the sampling methodology is negligible for the modeled coastal and inland flooding combined.

Standard Verified

KCC Meets Standard SF-5: Replication of Known Flood Losses

- The KCC US Flood Reference Model estimates flood losses in an unbiased manner as has been demonstrated by historical comparisons, including recent events, for personal residential exposures. The model loss comparisons have been completed at a ZIP Code resolution, which is appropriate for ascertaining any bias in the model.

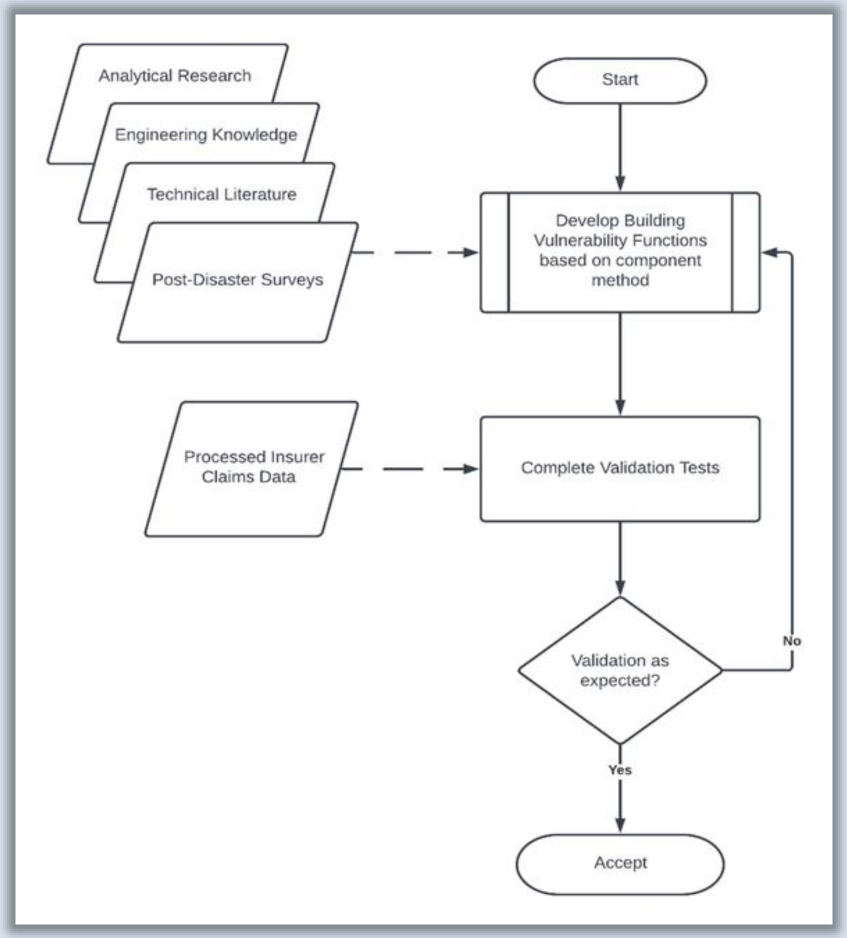
Table 7 - Comparisons of modeled losses to disguised insurer flood losses

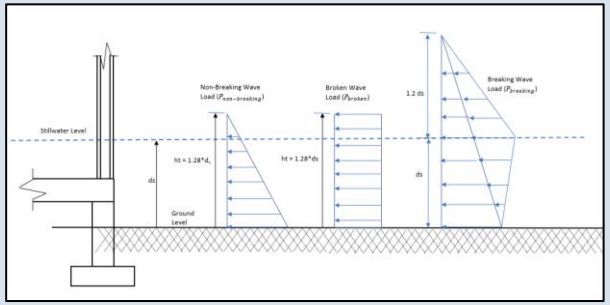
Event	Classification	Actual	Modeled
Hurricane Hermine (2016)	Coastal	80,885,013	66,612,669
Hurricane Matthew (2016)	Coastal	288,536,961	298,026,058
Hurricane Michael (2018)	Coastal	352,269,119	140,200,937
Hurricane Sally (2020)	Coastal	234,452,684	271,257,810
Total Coastal	**Coastal**	**956,143,777**	**776,097,474**
March 30, 2009	Inland	3,446,260	11,929,062
May 15, 2009	Inland	20,898,003	31,392,662
December 12, 2009	Inland	209,079	893,864
June 9, 2012	Inland	17,609,365	22,695,996
June 22, 2012	Inland	64,978,634	93,111,549
July 3, 2013	Inland	19,137,927	31,034,375
April 30, 2014	Inland	98,910,055	91,372,045
October 21, 2014	Inland	256,418	16,360,564
June 22, 2017	Inland	3,830	-
August 27, 2017	Inland	30,852,224	38,074,286
Total Inland	**Inland**	**256,301,794**	**336,864,405**
Hurricane Irma (2017)	Combined	1,474,762,040	1,821,623,500
Total Combined	**Combined**	**1,474,762,040**	**1,821,623,500**
Total of Events	**Coastal, Inland, Combined**	**2,687,207,612**	**2,934,585,380**

KCC Meets Standard VF-1: Derivation of Building Flood Vulnerability Functions

- The KCC building flood vulnerability functions were developed based on rational structural analysis, post-event site surveys, technical literature, and expert opinion. Insurance claims data for historical events were used to validate the vulnerability functions. Throughout the vulnerability function development process, KCC engineers referred to current scientific research and accepted flood engineering principles. Flood vulnerability functions are consistent with historical and other relevant data.

- KCC engineers ensured that the vulnerability functions and related uncertainties comply with fundamental engineering principles and are theoretically sound. The vulnerability functions were developed and validated by experts in structural engineering and are based on published research, post-event site surveys, expert opinion, and rational structural analysis. The uncertainties associated with each damage level were developed based on sound statistical and engineering principles.





Standard Verified

KCC Meets Standard VF-1: Derivation of Building Flood Vulnerability Functions

- The KCC building stock classification is representative of the personal residential buildings found in Florida. The building inventory and stock information was compiled from published studies on the Florida residential building stock, census and tax appraiser's data, public information from FEMA's HAZUS program, damage survey observations, and the Florida Hurricane Catastrophe Fund (FHCF) 2023 dataset. These data were then used to identify and classify the relevant building construction types.
- The KCC vulnerability functions use the inundation depth above ground as the input to calculate the level of damage. The derivation of the vulnerability functions accounts for the hydrostatic and hydrodynamic loading from inundation depth and damaging wave action in coastal areas. The vulnerability functions are derived using a building component-based analysis, in which the vertical and lateral hydrostatic, hydrodynamic, and wave-action forces at different inundation depths are calculated for affected building components. All these forces are separately calculated and then combined and compared with the building component resistances to develop the vulnerability functions.

Construction Type

Site Built Home
Wood Frame
Unreinforced Masonry
Reinforced Masonry
Reinforced Concrete
Steel
Light Metal
Masonry
Unknown

KCC Meets Standard VF-1: Derivation of Building Flood Vulnerability Functions

- Lowest floor elevation relative to the ground, foundation type, construction materials, number of stories, and year of construction have been accounted for in the derivation of personal residential building vulnerability functions. In the KCC US Flood Reference Model, the lowest floor elevation relative to the ground is called first floor height (FFH). This is the same as the lowest floor elevation definition for NFIP Zone A. The same definition is used in both inland and coastal flood vulnerability functions. Different vulnerability functions have been derived for buildings with different FFHs.
- Manufactured home and personal residential building structure vulnerability functions were derived separately.

Example Primary Characteristics: Stories and Construction Type

Number of Stories
1
2
3
4
5
6
7
8
9
10
Over 10
Unknown

Manufactured Home
Full Tie-Downs
Partial Tie-Downs
No Tie-Downs
Unknown

KCC Meets Standard VF-2: Derivation of Contents Flood Vulnerability Functions

- The personal residential contents flood vulnerability functions were developed based on technical literature review, engineering judgement informed by rational structural analysis, and post-event damage surveys. Vulnerability functions were then validated using insurance claims data.
- The relationship between modeled building vulnerability functions and modeled contents vulnerability functions is reasonable and has been validated with insurance claims data.

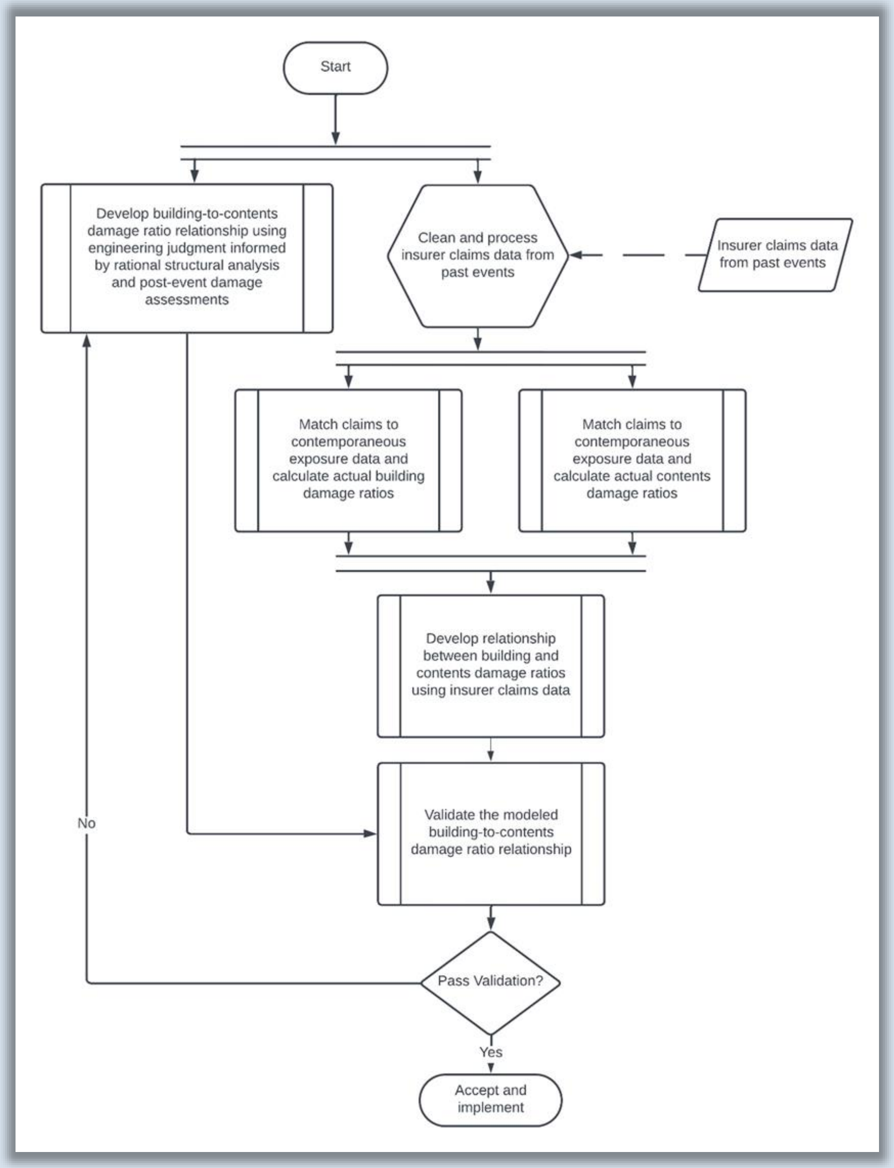


Table 14 - Claims data used to validate the modeled relationship

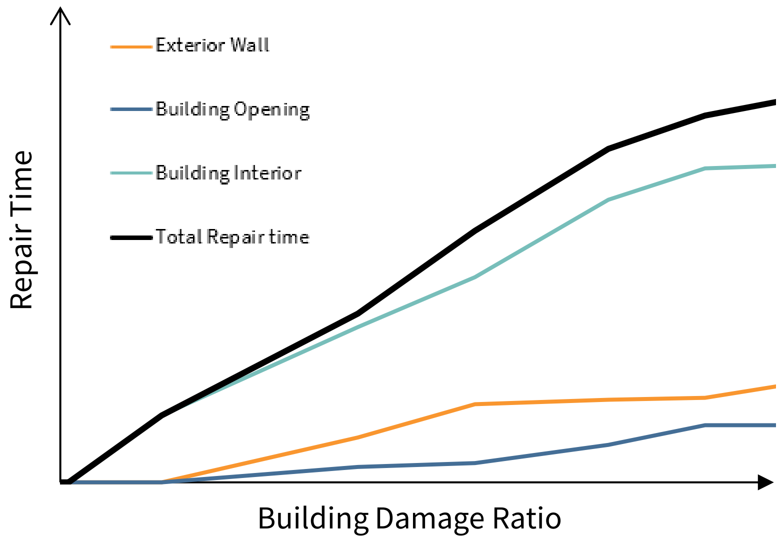
Policy Type	Number of Policies	Exposure ($)
Personal Residential	19,341,801	1,092,864,734,859
Manufactured Homes	15,539	449,903,200

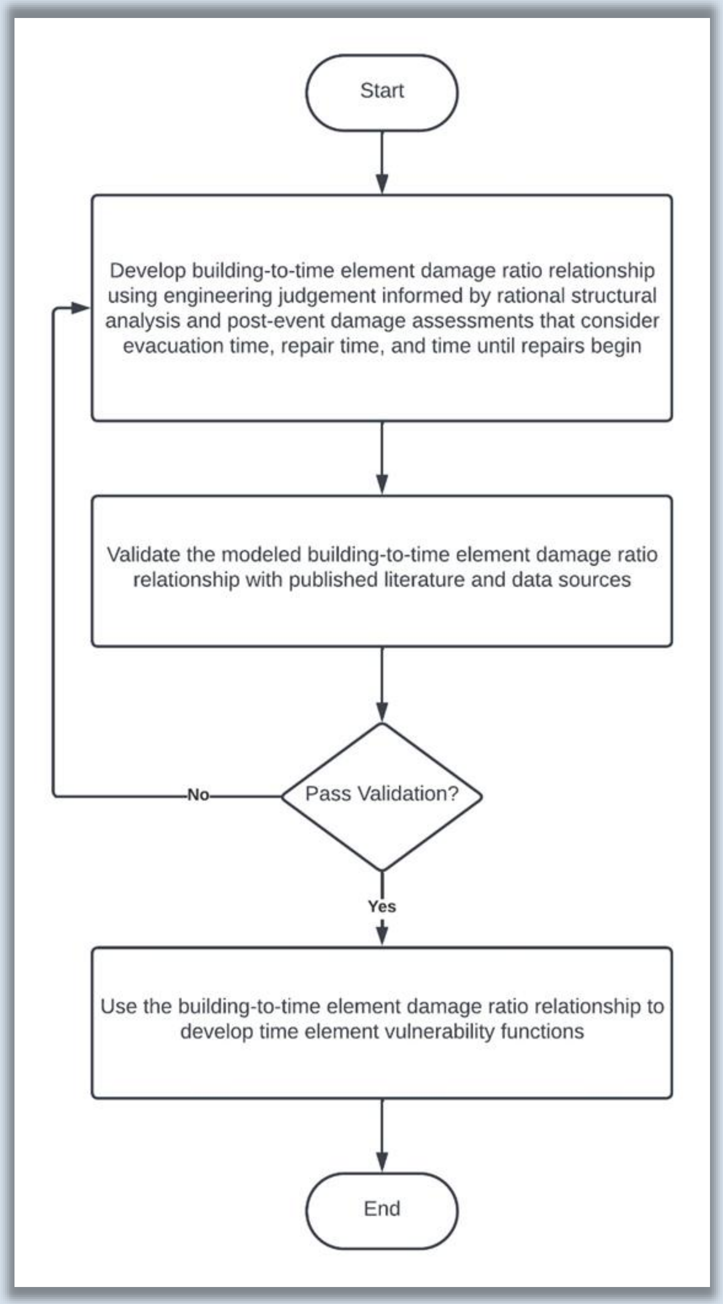
Standard Verified

KCC Meets Standard VF-3: Derivation of Time Element Flood Vulnerability Functions

- The time element flood vulnerability functions were developed based on engineering judgement informed by rational structural analysis and post-event damage surveys.
- The relationship between modeled building, time element, and contents vulnerability functions is reasonable.
- The estimated time required to repair or replace the property was considered in the derivations of time element flood vulnerability functions.

Repair Time by Example Building Component





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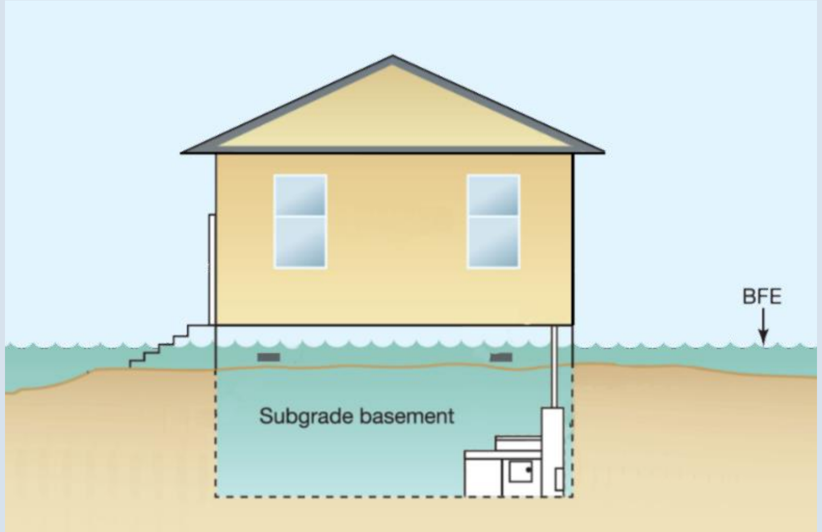
KCC Meets Standard VF-4: Flood Mitigation Measures

- The impact of mitigation measures and secondary characteristics on a building's flood load resistance is captured through the use of modification factors that increase or decrease the building vulnerability functions. The default vulnerability functions are those developed for the distinct combinations of primary building characteristics described in Standard VF-1. The secondary characteristics relevant to building flood vulnerability include type of basement, opening protection, wall-to-foundation connection, and type of mitigation measure. For each secondary characteristic, detailed engineering analysis, supported by post-event damage survey data, and engineering judgement are used to determine its effects on overall building performance.

- The mitigation measures and secondary building characteristics included in the KCC US Flood Reference Model have been justified and well documented with respect to their impacts on building performance during flooding.

Example of Dry Floodproofing (FEMA)

Example of Basement (FEMA)



Standard Verified

KCC Meets Standard VF-4: Flood Mitigation Measures

- The application of flood mitigation measures is justified by sound structural engineering analysis. Each mitigation measure impacts the vulnerability function of a related building component(s) and consequently modifies the building vulnerability function. The effect of each flood mitigation measure is estimated separately. If more than one mitigation measure is present, the effects of multiple mitigation measures are combined systematically, as described in Standard VF-4, Disclosure 7. The application of individual or a combination of flood mitigation measures and the resulting vulnerability functions are reasonable and in agreement with engineering principles.

Example of Combination in Form VF-3: elevating utility equipment is one of the sub-measures of wet floodproofing

Wet 1 Foot	0.0	3.9	33.7	9.6	2.7	8.1	40.0	11.6	3.8	0.7
Wet 2 Feet	0.0	3.9	80.0	25.2	6.5	8.1	84.3	29.4	8.6	1.5
Wet 3 Feet	0.0	3.9	80.0	37.6	13.4	8.1	84.3	43.5	16.1	2.5

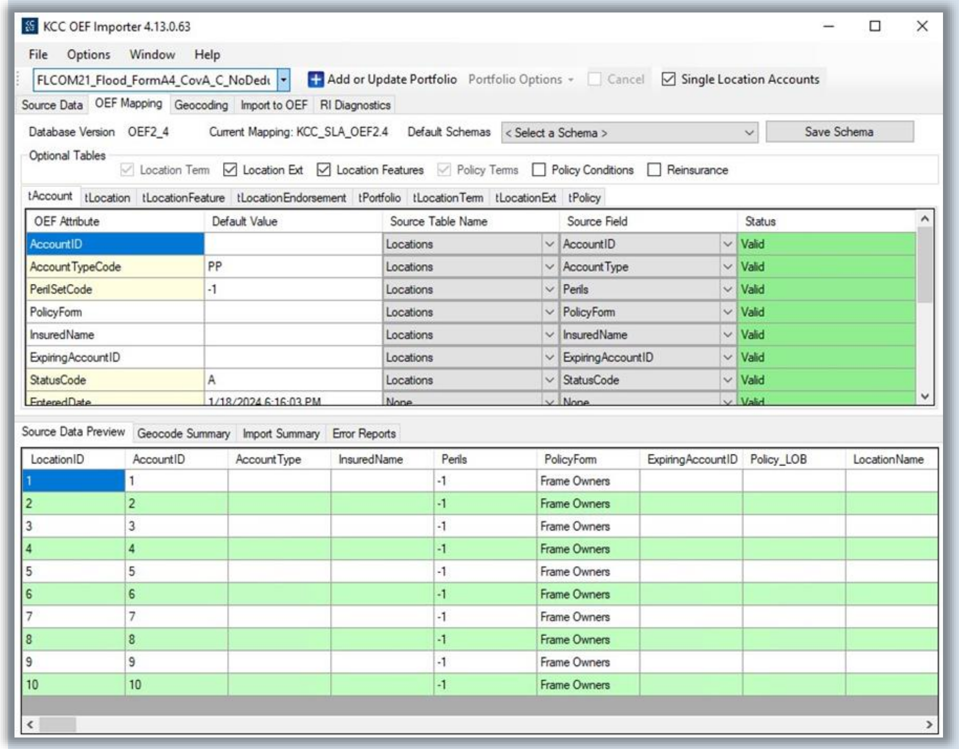
Elevate Utility Equipment 2 Feet Above Floor and Wet Floodproof Structure to 2 Feet	0.0	3.9	80.0	25.2	6.5	8.1	84.3	29.4	8.6	1.5

KCC Meets Standard AF-1: Flood Model Input Data and Output Reports

- All adjustments, edits, inclusions, or deletions to insurance company input or other input data are based upon accepted actuarial, underwriting, and statistical procedures.

- Model input data are provided by the user for each catastrophe loss analysis. RiskInsight® performs validation tests during exposure data import and includes exposure data validation tools within the user interface that assist users in verifying data integrity. All modifications, adjustments, assumptions, inputs and input file identification, and defaults necessary to use the flood model are actuarially sound and are included with the flood model output report and in the RiskInsight® documentation. Treatment of missing values required to run the flood model are actuarially sound and described in the RiskInsight® documentation.

Options available on exposure data import



Standard Verified

KCC Meets Standard AF-2: Flood Events Resulting in Modeled Flood Losses

- Modeled flood loss costs and flood probable maximum loss levels reflect insured flood related damages from coastal and inland flood events impacting Florida.
- KCC has a documented procedure for distinguishing flood losses from other peril losses.
- These documents were reviewed by the Professional Team during the remote review.

KCC documentation includes clear procedures for distinguishing flood losses from other peril losses.

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KCC Meets Standard AF-3: Flood Coverages

- The KCC US Flood Reference Model calculates building, appurtenant structure, contents, and time element loss costs separately from appurtenant structures, contents, and time element flood loss costs. The methods used in the calculation of flood loss costs are actuarially sound.

Standard Verified

KCC Meets Standard AF-4: Modeled Flood Loss Cost and Flood Probable Maximum Loss Level Considerations

- The KCC US Flood Reference Model generates loss estimates which do not include expenses, risk load, investment income, premium reserves, taxes, assessments, or profit margin. As a result, the flood loss cost projections and probable maximum loss levels included in this submission do not include any of those elements.

- The KCC US Flood Reference Model uses the replacement values and policy terms that the user inputs without any adjustments and consequently does not make a prospective provision for economic inflation in the flood loss cost projections and probable maximum loss levels.

- Flood loss cost projections and flood probable maximum loss levels solely include inland and coastal flood losses and do not include any explicit provision for wind losses.

- The KCC US Flood Reference Model considers damage caused by both inland and coastal flooding, which are included in the calculation of flood loss costs and flood probable maximum loss levels.

- In the KCC US Flood Reference Model, the flood loss cost projections and flood probable maximum loss levels can be calculated at a specific location level. Flood loss cost projections and flood probable maximum loss levels can then be calculated at any geographic level desired, including the geocode (latitude-longitude) level of resolution.

- Demand surge—the increase in the repair or replacement cost of a damaged property, which may occur following a large-scale disaster due to a limited supply of labor, equipment, reconstruction materials, and financing—is included in the KCC US Flood Reference Model's calculation of flood loss costs and flood probable maximum loss levels. The demand surge function has been developed using relevant data and actuarially sound methods and assumptions.

Standard Verified

KCC Meets Standard AF-5: Flood Policy Conditions

- The methods used in the development of mathematical distributions that reflect the effects of deductibles, policy limits, and flood policy exclusions are actuarially sound.

- The model generates MDRs, which represent the cost to repair the damage divided by the replacement value of the property. For each MDR, the model considers the secondary uncertainty, which is the full probability distribution of damage levels around the mean, using non-parametric distributions. The secondary uncertainty distribution is used to apply the effects of deductibles and limits.

$$Expected\ Insured\ Loss = \int_{x=0}^{1} f_{\bar{D}}(x)\{Coins\% * \max[0, \min(PL, x * RV - DED)]\}dx$$

where

$f_{\bar{D}}(x)$	= Secondary Uncertainty Distribution
Coins%	= Coinsurance Percentage
X	= Damage Ratio
RV	= Replacement Value
PL	= Policy Limit
DED	= Deductible

In application, $f_{\bar{D}}(x)$ is discretized and numerical integration is used to estimate the expected insured loss.

- The relationship among the modeled deductible flood loss costs is reasonable.

- Deductible flood loss costs are calculated in accordance with s.627.715, F.S.

Standard Verified

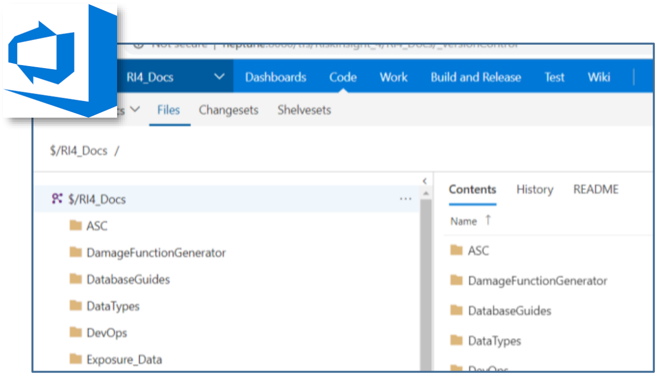
KCC Meets Standard AF-6: Flood Loss Outputs and Logical Relationships to Risk

- The methods, data, and assumptions used in the estimation of the flood loss costs and flood probable maximum loss levels in the KCC US Flood Reference Model are actuarially sound.
- The KCC US Flood Reference Model produces flood lost costs that exhibit a logical relation to risk and that do not exhibit a significant change when the underlying risk does not change significantly. No alternate relationship has been observed in the loss costs.
- All else held constant:
  - Flood losses in the KCC US Flood Reference Model do not increase as flood damage resistance increases
  - Flood loss costs do not increase as flood hazard mitigation measures increase
  - Flood loss costs are consistent with the effects of major flood control measures
  - Flood loss costs do not increase as the flood resistant design provisions increase
  - Flood loss costs do not increase as building code enforcement increases
  - Flood loss costs decrease as deductibles increase, all else held constant
- The relationship of flood loss costs in the KCC US Flood Reference Model for individual coverages is consistent with the coverages provided. No alternate relationship has been observed in the loss costs.
- Flood output ranges are logical for the type of risk being modeled. There are no apparent deviations in the flood output ranges.
- All else held constant, flood output ranges reflect a higher flood loss cost for personal residential structures at a lower elevation and a lower loss cost for those at higher elevations. No alternate relationship has been observed in the loss costs.
- For the flood loss costs and flood PML level estimates derived from and validated with historical insured flood losses or other input data and information, the assumptions in the derivations concern construction characteristics, policy provisions, and contractual provisions are appropriate for the type of risk being modeled.

Standard Verified

KCC Meets Standard CIF-1: Flood Model Documentation

- KCC maintains:
  - Two sets of documents on model functionality and technical descriptions: one for external client use and the other set for internal use. All KCC documentation is managed through a version control system
  - A primary document repository containing a complete set of documentation aligned with software engineering practices using Microsoft TFS. KCC uses generally accepted procedures to ensure the documents are readable, self-contained, and easy to understand. All system components are documented with requirement statements, class, data flow, and sequence diagrams as appropriate while providing relevant detail on the structure and flow of data between the components and subcomponents.
  - Pertinent computer software documents based on documentation templates that are consistently dated.
  - A table of all changes to the software and data files associated with the flood model that was reviewed by the Professional Team.
  - A list of all externally acquired software and data assets that was reviewed by the Professional Team.
- The model, software, and database schema are documented separately from the source code.



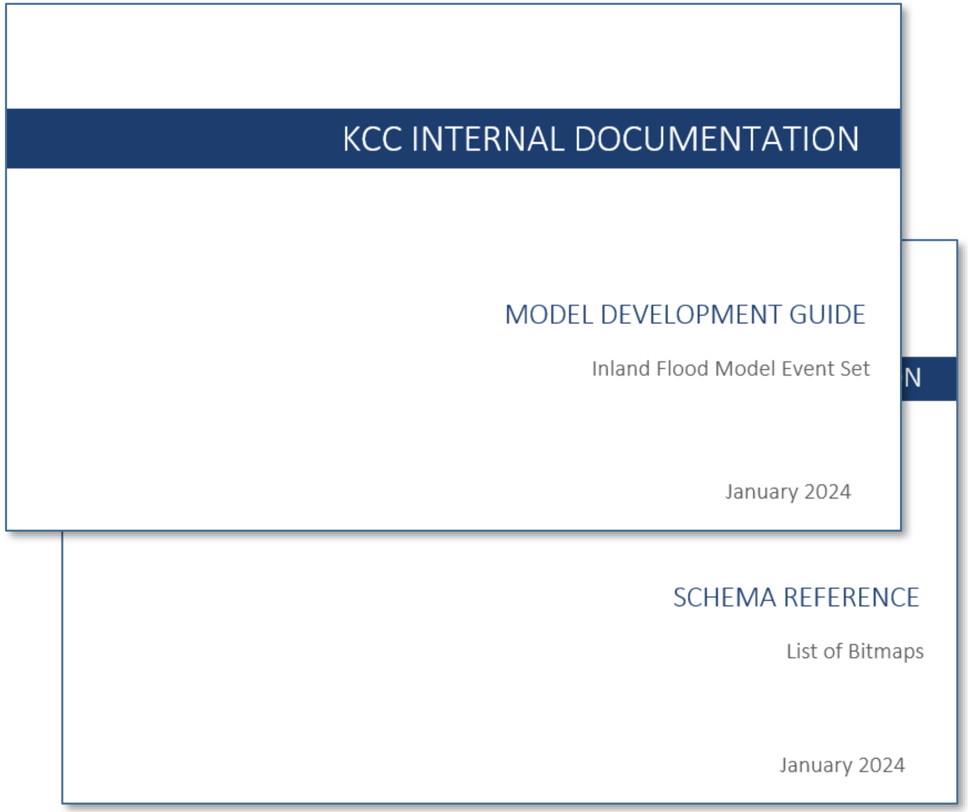
Example documentation folders in TFS

Example KCC software external user documentation

Standard Verified

KCC Meets Standard CIF-2: Flood Model Requirements

- KCC maintains requirement statements for each software component and schema documentation for each database and file accessed by the component.
- KCC documents, as appropriate, are updated when pertinent changes are made to the flood model and managed through source control.



Example KCC documentation maintained for software components and schemas

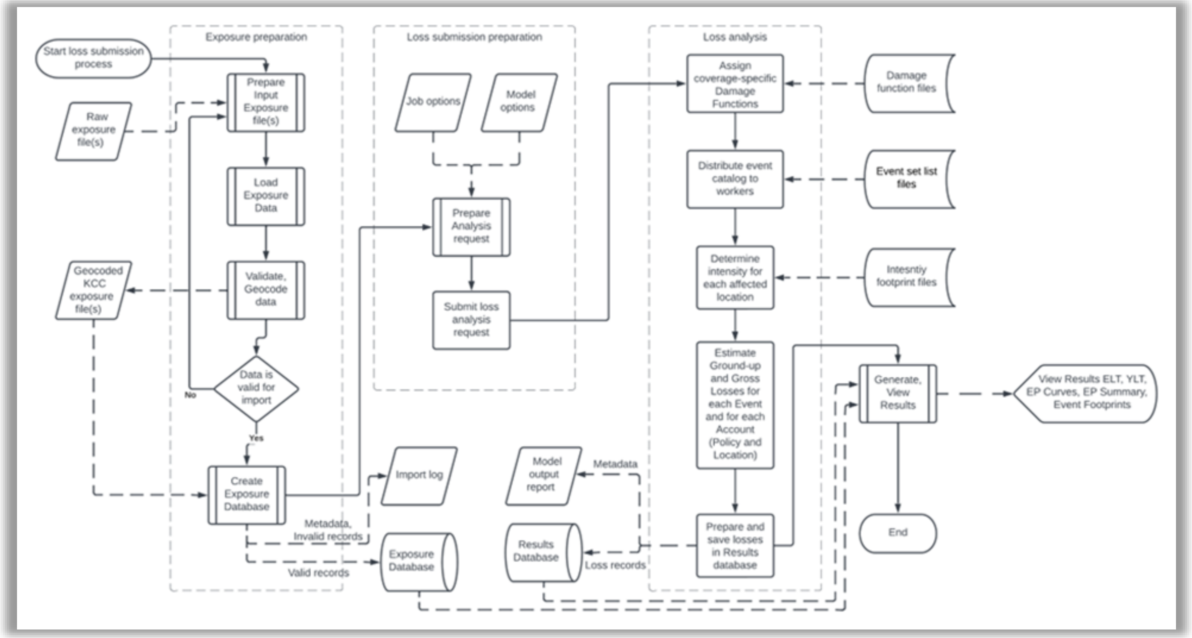
Standard Verified

KCC Meets Standard CIF-3: Flood Model Organization and Component Design

- KCC maintains documents that describe the flow of data between all relevant components of the software as well as the schema of the databases that host the exposures, results, and supporting API. Documentation is maintained and managed within source control.

- All flowcharts developed and maintained by KCC conform to the ISO 5807 standard, including the KCC Appendix to the standard.
  - Figure 55 on the right shows an example flowchart employed within KCC documentation standards

Figure 55 – Sample flowchart employed in KCC documentation standards



Standard Verified

KCC Meets Standard CIF-4: Flood Model Implementation

- KCC maintains documentation for:
  - Implementation procedures and coding guidelines to ensure all software components comply with our coding standards.
  - Diagrams and documentation on the organization of the networks where the flood model is installed
  - Procedures for creating and verifying databases and data files accessed by the software
  - A table of all software components affecting flood loss costs and flood probable maximum loss levels.
  - A list of all equations and formulas used in documentation of the flood model with definitions of all terms and variables
  - A cross-referenced list of implementation source code terms and variable names
  - Procedures for updating data and software used for flood model development

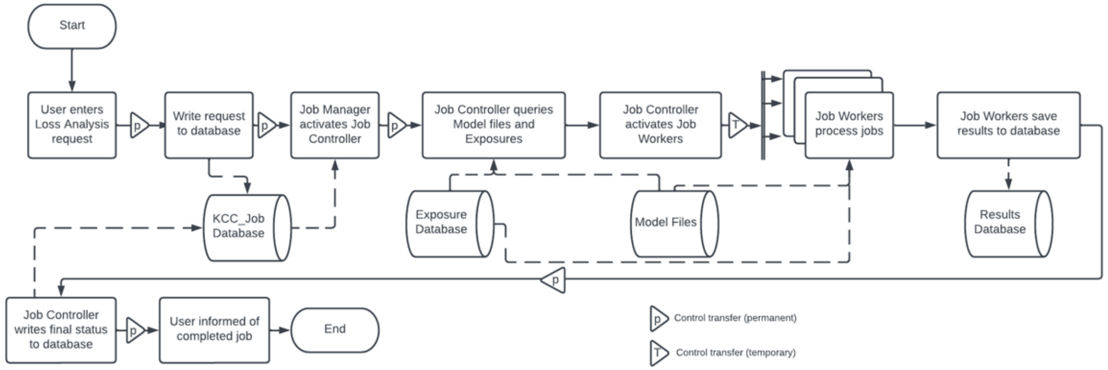


Figure 4 - KCC Network Organization Diagram

- KCC guidelines require all components to be explicitly and clearly identified and traceable down to the code level. KCC coding guidelines require the code for all components to be clearly named and documented for efficient transfer of knowledge between any two software engineers broadly familiar with the subject matter. KCC standards also require all code changes to pass a formal code review process using Microsoft TFS or GitHub.

KCC Meets Standard CIF-5: Flood Model Verification

General Overview

KCC employs multiple procedures to verify code correctness. Members of the model development team independently develop prototypes and worked examples of the desired software implementation for key components. The prototypes and worked examples are shared with the KCC software team, along with representative output prior to implementation.

All code implementations as well as the principal outputs are subject to code reviews and tests by the primary developers and by experienced developers using appropriate combinations of hand calculations, unit tests, and visual inspection of graphical representations before being released from the software development (DEV) environment to the quality assurance (QA) environment. The QA environment is then used by other KCC professionals (not software engineers) to independently verify the model's intermediate and final outputs and to perform regression tests.

KCC professionals other than the original component developer conduct rigorous QA checks of the model output for each build of the software, including reviews of any component that has changed from the previous build. The results of the QA checks are verified against expected outputs with relevant members of the software and research teams to ensure code correctness.

Testing

KCC uses both Microsoft Team Foundation Server and Git/GitHub for managing source code, documentation, test plans and project management.

Unit tests are written using NUnit and are executed by Github. A history for each unit test is maintained on Github. The software development team is notified immediately when a test fails. Github provides access to the build history and test runs. Code check-ins that cause a test to fail and code check-ins that resolve a failed test are linked from the test history.

Regression and aggregation tests are run nightly . Regression tests are performed and documented for each build released to QA.

All externally provided data, software, and models undergo extensive verification by subject matter experts.

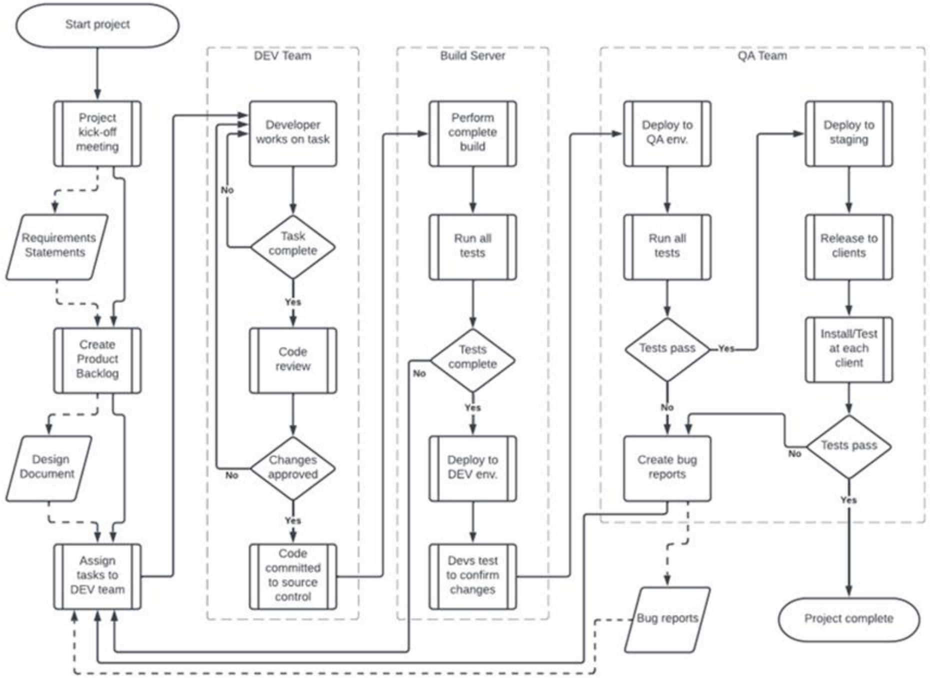


Figure 56 – Flowchart for testing software components prior to release

Standard Verified

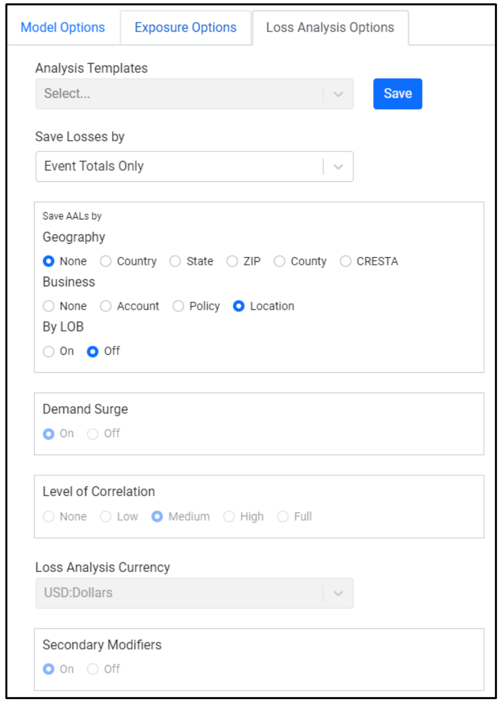
KCC Meets Standard CIF-6: Human-Computer Interaction

- The RiskInsight user interface adheres to accepted principles* for user interface design to implement an intuitive and informative user experience utilizing Microsoft Windows Forms, React JS and Leaflet JS.*
  - Example principles:
    - Spacing and Positioning
    - Size
    - Grouping
    - Intuitiveness

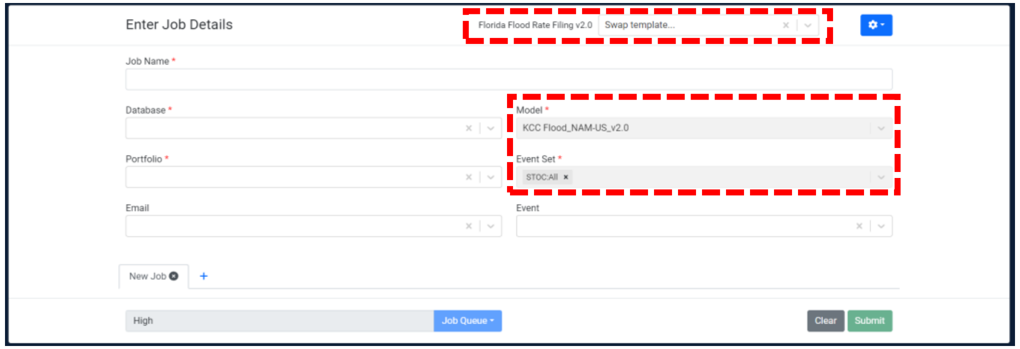
- RiskInsight user interface options leverage distinct and explicit dropdowns and radio buttons to determine options used in flood model analysis.

- RiskInsight provides a pre-defined, read-only loss analysis options template which automatically selects only the options found acceptable by the Commission for rate filing in the state of Florida, shown in the image on the righthand side.

Loss Analysis UI – Clear Options for Analysis



Loss Analysis UI – Florida Rate Filing Template



KCC Meets Standard CIF-7: Flood Model Maintenance and Revision

KCC has a robust procedure to ensure complete and accurate completion of development projects, including:

- **In-Person Kick-off Meetings** are used to define a project, assign tasks, and initiate the project; these are accompanied by text-based notes and requirements statements
- **Team Foundation Server (TFS)** and **GitHub** integrate with Visual Studio to provide developers with software requirements, work-item tasks, and a full-featured code comparison tool
- **Peer Reviews** occur periodically as a developer works on an item to ensure that KCC coding standards are met and verify the efficiency of the code
- **Code Reviews** occur after an item passes peer review and is complete; check-ins cannot occur without a code review
- **Automated Tests** are executed on all checked-in code, including tests for each code-check in and a nightly build for an extended set of integration tests
- **Documentation** is used throughout the software development process, including Test plans, Software Design Documents, and Software Requirement Specifications, all of which are maintained through TFS and accessible through Visual Studio
- **SME Verification**: Subject matter experts (SMEs) perform component resolution reviews to verify model output is consistent with the intended changes introduced during a model update.

- KCC uses Microsoft TFS and GitHub to report errors and track software updates, data versions, and documentation.
    - Any revision to the flood model will result in a unique flood model version identification number

- KCC maintains a list of all changes to the flood model version that was reviewed with the Professional Team.

Standard Verified

KCC Meets Standard CIF-8: Flood Model Security

- KCC employs security measures and procedures at several levels to ensure the code, data, and documentation is secure, including:
  - **Physical Security** – The building employs 24-hour security personal and is restricted with electronic badge system. Only KCC employees may enter offices, and only administrators have access to locked data room within KCC offices.
  - **Network Security** – FortiGate firewalls are used to control all traffic in and out of network. External access is granted using VPN gateway, and internal access is controlled by windows permissions.
  - **Sever and Workstation Security** – All servers are located in secured data room, only accessible by administrators. All work stations receive regular windows updates and patches, and are protected with anti-virus software.
  - **Data Security** – All confidential data can be sent via SFTP with encryption. Data access and file storage are restricted to only authorized users. Only software developers have access to KCC code through Microsoft TFS and Github.
  - **User Management** – All company personnel are required to sign NDAs and complete a background check. Email access is secured through MFA, and workstations require authorized user accounts for access.

Standard Verified

