TECHNICAL DOCUMENTATION

UrbanFootprint Coastal Flood Loss Methodology

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Overview

UrbanFootprint estimates structural losses resulting from coastal flooding due to tropical storm surge inundation. These loss estimates are derived using depth damage functions provided by FEMA's Hazus program and distributed via the open-source Hazus Flood Assessment Structure Tool (FAST). Hazus, a FEMA-developed methodology, estimates physical damage to asset archetypes due to natural hazards. Depth damage functions relate flood depth to the percentage of structural damage expected for a given asset, incorporating a variety of structural and environmental characteristics. While Hazus provides functions for various flood types, this analysis focuses specifically on losses due to hurricane storm surge. It is important to note that these estimates do not include losses from other flood sources, such as tidal flooding or inland flooding due to rainfall. Both annual expected losses and conditional losses by hurricane category are estimated.

Loss Functions

Hazus depth damage functions, accessed via the Flood Assessment Structure Tool, estimate the percent of damage to a structure at each one-foot increment of flood water depth. Hazus provides depth damage curves for various types of flooding, including riverine and coastal flooding. This work focuses on losses due to coastal flooding specifically.

Hazus Archetypes

FEMA's Hazus program defines asset archetypes, which are categories of buildings with similar vulnerability to flood hazards. Archetypes for flooding, described in the Hazus flood loss documentation, are characterized by a combination of structural and environmental characteristics, occupancy type, presence or absence of a basement, foundation height, number of stories and flood zone. The specific set of components defining an archetype varies, and only a few components are consistently required across all archetypes.

Structure Characteristics

To provide loss estimates across the U.S. we utilize data from the National Structure Inventory (NSI), supplemented with UrbanFootprint's Base Canvas parcel data. The NSI, maintained by the U.S. Army Corps of Engineers, is a database that catalogs structures across the United States, primarily to support risk assessments for natural hazards. Table 1 identifies the structural characteristics needed to implement Hazus depth damage functions. While the NSI data contains all necessary structure characteristics, some parcels in the UrbanFootprint Base Canvas lack corresponding structure data within the NSI dataset. Where we have reason to believe a structure should exist on a parcel, we infer the missing structural data using the median or mode of the structure characteristic based on neighboring parcels with the same UrbanFootprint land use classification.

Table 1. Sources and methodology for structural characteristics used in matching the Hazus damage function with individual structures.

Structure Characteristic	**Source**	**Methodology**	**Required for every archetype**
Occupancy Type	NSI	The National Structure Inventory (NSI) point data was spatially joined to Base Canvas parcel polygons to assign parcel data to structures. Where parcels lacked corresponding NSI points, missing attribute values were imputed using mode or median calculations, based on the proximity and land use classification of neighboring UF parcels.	Y
Presence of Basement	NSI		N
Foundation Height	NSI		Y
Number of Stories	NSI		N

Environmental Factors

Hazus provides default depth damage functions for zone A and V flood zones in coastal areas. These zones represent distinct flood risk characteristics. V zones are typically located closest to the shoreline and are subject to both inundation from storm surge and the additional destructive forces of waves. This direct wave action can cause significant structural damage beyond simple inundation. A zones, in contrast, are primarily subject to inundation from storm surge, without the added wave-related forces.

To determine the appropriate flood zone for each structure, we spatially join the structure data with FEMA's National Flood Hazard Layer (NFHL). For parcels without corresponding NSI structure location data, we use the parcel centroid as the structure's location. The NFHL data contains a number of different flood zone codes including A zones (A, AO, AH, AE, and A99), V zones (V and VE), D zones, X zones, open water and unmapped areas.

We reassign any flood zone types other than A or V to A zones for the purpose of assigning an appropriate damage function.

Storm Surge Inundation Data

UrbanFootprint Coastal Flood Probabilities

The UrbanFootprint Coastal Flood model assesses the risk of inundation from storm-related events, specifically those driven by tropical cyclones, for both current and future climate scenarios. The model estimates annual exceedance probabilities for storm surge depths ranging from 0 to 24 feet in 1-foot increments, at a parcel scale. Current coastal flooding risk is estimated by connecting storm surge inundation depths from the NOAA SLOSH model by hurricane category with hurricane category probabilities from UrbanFootprint's Hurricane Winds model. Future risk also incorporates the long-term risk of sea level rise.

Adjusting First Floor Elevation

Hazus depth damage functions for structural loss relate damage percentage to water inundation depth, measured relative to the top of the first finished floor. As a result, first floor elevation, the height of a building's first finished floor above ground, is one of the more important variables in determining storm surge damage. Because Hazus depth damage functions use flood depths relative to first floor elevation, they support negative flood depth values. A depth of -4 feet, the lowest depth supported, indicates 1 foot of inundation in the basement of a structure and -1 indicating that the basement of the structure is completely inundated.

UrbanFootprint's coastal flood inundation depth data is defined relative to the ground elevation. To align this with the Hazus requirement of flood inundation relative to first floor elevation, we use foundation type data from the NSI to estimate the foundation height for each structure. This estimated foundation height is then used to adjust the depth damage function for each structure. For a storm surge depth d, a damage function $f(d)$, and a foundation height h, an adjusted damage function $f'(d,h)$ is defined as $f'(d,h) = f(d-h)$. We assume that $f(d)$ is constant for $d \leq -4$ and $d \geq 24$, which are the minimum and maximum values provided for the damage functions, respectively.

Note that because UrbanFootprint coastal flood estimates are relative to ground elevation, we do not capture flood inundation events where a basement is flooded while the street above is not flooded. Consequently, the negative flood inundation depths resulting from the above foundation height adjustment occur only when there is at least some level of flooding at ground level.

Loss Estimation

There are many ways to estimate "value" lost to coastal flooding. We focus on estimating the impact of storm-related inundation on a structure's assessed improvement value. This provides a proxy for potential impacts of storm surge inundation damage on property tax revenue. Loss estimates are calculated for structures associated with parcels with residential, commercial and industrial land uses. Losses for other land uses, such as transportation utilities (e.g. airports, transit stations and parking structures) and civic institutions (e.g. universities, schools, police and fire stations, hospitals, and civic facilities like libraries), are not supported at this time.

Assessed Improvement Value Null Filling

Loss estimates are directly proportional to the structural value on which we apply the damage curves. As mentioned previously, we calculate the loss to the assessed improvement value on each structure, representing the potential loss of tax revenue due to structural damage. However, assessed improvement value is not always available. We obtain various property value data including market value, total value, assessed value, assessed improvement value, and market improvement value from multiple sources with varying coverage. When assessed improvement value data is unavailable for a specific parcel, we use other available value data to estimate it. This estimation provides full coverage of parcel level assessed improvement value, representing the total assessed value of all structures on the parcel. This parcel-level assessed improvement value is then disaggregated to individual structural values based on structure-level characteristics.

Annual Expected Loss

Annual expected loss is defined as

$$\mathrm{AnnualExpectedLoss} = \sum_{d=0}^{24} L_d \times \mathrm{AssessedImprovementValue} \times P_d$$

where L_d is the loss ratio for a given inundation depth d, and P_d is the annual probability of that inundation depth. This equation relies on marginal probabilities for the inundation depth. Because UrbanFootprint's Coastal Flood data is provided as exceedance probabilities, which measure the probability of a given inundation depth or higher, we marginalize the exceedance probabilities before estimating losses. While we apply this relationship to assessed improvement value to estimate potential tax impacts, other types of value data could be used instead to estimate losses from other perspectives.

Conditional Losses by Storm Category

Conditional losses, representing potential losses given a specific storm event, can be calculated for each inundation depth by multiplying the loss ratio for that depth L_d by the assessed improvement value of the structure. These conditional losses by inundation depth can then be used to estimate conditional losses by tropic cyclone category. For each category of hurricane on the Saffir-Simpson scale we use the NOAA SLOSH model Maximum of Maximum Envelope of High Water (MOM) data, representing a “worst-case” scenario of storm surge inundation. It is important to note that in reality, storm surge inundation can vary widely for a given hurricane category, as categories are defined based on wind speed exclusively. To estimate the conditional loss due to a worst-case storm of a given category, we simply multiply each structure’s assessed improvement value by the depth damage function value corresponding to the MOM-derived inundation depth for that structure and storm category.

