Climate Ready Boston

Approach and Methodology for Asset Data Collection and Exposure and Consequence Analysis

CONTENTS

TABLES AND FIGURES

1. INTRODUCTION

The Climate Ready Boston (CRB) Vulnerability Assessment reviews three climate-related hazards and their plausible evolution over time to analyze how the City can expect people, property, infrastructure, and the economy to be affected by such hazards: 1) chronic stresses of extreme heat; 2) frequent impacts from stormwater flooding; and 3) frequent and acute events of coastal and riverine flooding. Within the CRB Vulnerability Assessment is an evaluation of exposure and consequences of the three hazards, including an evaluation of potential quantified losses due to coastal and riverine flood impacts. Losses considered for the analysis include structure damage, contents and inventory losses, displacement costs, shelter needs, business interruption losses to the local economy, and stress factors on the human population. Additional exposure evaluations for coastal and riverine flooding consider property value (building and land), as well as number and types of buildings and people, as well as known infrastructure, that are within harm's way.

This Appendix includes a description of the approach CRB analysts developed to conduct the exposure and consequence analysis, including detail on the data gathering process and methods used to evaluate exposure to various hazards and the consequences of coastal and riverine flooding. All values within this approach are estimates based on hypothetical and modeled hazard scenarios, and known and unknown data limitations exist. These limitations are described where known. Real impacts of coastal and riverine flooding will differ based on the particulars of the event as it happens. Refer to the **Hazard Data Development Appendix** for more detail on how hazard data was acquired and processed for use in the CRB Vulnerability Assessment. Detailed results of the exposure and consequence analyses are provided in the **Detailed Result Appendix.**

The Appendix is organized as follows:

- **Asset Inventory and Development.** CRB developed a detailed asset inventory to capture exposure of Boston's people, property, economy, and infrastructure to heat and flood hazards, and to examine the expected consequences of coastal and riverine flooding, more specifically. The asset inventory is comprised of two datasets that work together to inform the exposure and consequence analysis: Building Information (attributes and analysis results) and Site-Specific Asset inventory (attributes only). The full asset inventory is comprised of over 130 separate datasets from a variety of sources. Steps required to collect the data and develop the asset inventory are described within this section.
- **Property.** The Property section within the Appendix describes the process CRB Analysts used to consider exposure of Bostonians' homes, businesses, schools, possessions, and more – at risk of impacts from stormwater flooding and coastal and riverine flooding. Refer to this section for

detailed descriptions on an analysis of structure exposure (types of buildings expected to be impacted by flooding), property value exposure (the taxable value of land exposed to flood impacts), infrastructure exposure (assets of particular importance to the City expected to be impacted by flooding), expected structure damage and contents losses, and expected costs of resident and business displacement (refer to Table 1 for detail).

- **People.** A key part of CRB is analyzing how climate-related hazards will impact Boston residents. The People section within the Appendix reviews the methods used to estimate the number of persons exposed or expected to be displaced as the result of an event, the number of people that may require shelter in a coastal or riverine flood event, and expected costs of mental stress and lost productivity due to coastal or riverine flood impacts.
- **Economy.** The Economy section within the Appendix describes the approach CRB analysts used to estimate disruption of business operations and job loss as a result of coastal and riverine flood impacts. Business interruption is quantified through loss of sales and revenues (output).

TABLE 1. LOSSES CONSIDERED FOR COASTAL AND RIVERINE FLOOD IMPACT ASSESSMENT

Impact Category	Loss Category	Losses Considered	Description
Property	Direct Physical Damages to Buildings	• Structure Damage • Content and Inventory Loss	Direct physical damages include the destruction and degradation of buildings as a result of coastal or riverine flooding and are quantifiable as monetary losses based on the expected 2016 replacement cost of impacted assets.
Property	Displacement	• One-time Displacement and Relocation Costs	Displacement and relocation costs are associated with moving a household or a business to a new location and resuming activity in that new location.
People	Stress Factors	• Mental Stress and Anxiety • Lost Productivity	Natural disasters threaten or cause the loss of health, social, and economic resources, which leads to psychological distress. Stress factors are a product of damage to people’s homes, and are quantified as treatment costs, as well as lost income to workers.
People	Shelter Needs	• Number of persons and households in need of public shelter	Shelter needs for coastal and riverine flood events are calculated as a function of flood depth and certain social vulnerability factors, such as age and income of the affected population.
Economy	Business Interruption	• Loss of Employment • Output Loss	Business interruption is associated income and output lost to the economy as a result of an event that disrupts the operations of the business, or the removal of a piece of real estate, both rental and sale properties, from the market as a result of disaster impacts.

1.2 Summary of Reporting Format

Loss estimations for people, property, and the economy presented in the CRB Vulnerability Assessment are reported both as one-time costs by event in total and by loss category, and as an annualized value for each sea level rise condition.[1] Annualized values represent the total of the product of single losses expected for each projected sea level rise condition and the chance of occurring in any given year. This method facilitates resiliency planning by allowing for comparison across areas and events, as well as expected losses in each sea level rise scenario.

Annualizing losses is one method used to "normalize" results of an evaluation (or even historical losses) in order to communicate risk. In fact, the definition of *risk* is often communicated as *probability x consequence*; this is exactly how annualized losses are calculated. Annualized losses can be used to compare the impacts of different events across time for mitigation planning purposes, and can even be used to compare the effects of entirely different hazards (so long as a probability of impact and potential costs of such impact can be derived). Expected relocation costs within the City as a result of 9 inches of sea level rise (near term sea level rise scenario) can be used to illustrate this point:

TABLE 2. ANNUALIZATION OF ESTIMATED RELOCATION COSTS FOR THE 9 INCH SEA LEVEL RISE SCENARIO

Event	One-time Event Consequences	Probability (Percent Annual Chance)	Annualized (Probability x Consequence)
10 percent (high probability)	$12,000,000	10 percent	$1,200,000
2 percent	$30,500,000	2 percent	$600,000
1 percent (lower probability)	$35,600,000	1 percent	$400,000
0.1 percent	$155,200,000	0.1 percent	$200,000
Total	*cannot be calculated*	-	$2,400,000

By annualizing the losses of this event, it becomes apparent that the *risk* (probability x consequence) associated with the 10 percent annual chance event is higher than the lowest probability event evaluated, despite the fact that one time event costs for the 10 percent annual chance are expected to

[1]Annualized values consider four of the five frequencies considered in this Vulnerability Assessment, including the 10 percent, 2 percent, 1 percent, and 0.1 percent annual chance flood. Direct damages for each of the flood frequencies for one sea level rise condition were multiplied by their percent chance of occurrence and then added together to yield the annualized value for one sea level rise condition. The annualized values in this report do not consider frequent flood events such as high tides or storms with a chance of occurrence greater than 10 percent.

be significantly lower. This informs the resiliency planner that properties within the 10 percent annual chance flood area should perhaps be prioritized for action prior to those at risk only to lower probability events.[2] Such a decision would need to be made in combination with other factors, such as criticality of a structure to the community.

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[2] Risk prioritization should take into consideration a variety of factors.

2. ASSET INVENTORY AND DEVELOPMENT

CRB analysts developed two sets of data that provide the foundation of the Vulnerability Assessment's exposure and impact analysis: building information, and site-specific asset information. The two datasets were developed separate of each other due to their source origins, to cross-reference information, and identify potential discrepancies. In addition, there is sensitive information in the site-specific asset inventory subject to non-disclosure agreements that warrants independent maintenance and storage, whereas the building information dataset can be freely shared. The exposure analysis related to infrastructure systems and other site-specific assets do not consider assets that were provided under a non-disclosure agreement; evaluation of such elements is described within the Vulnerability Assessment qualitatively and as allowable by agreements made with the individual entities. All structures, however, are included in the consequence analysis for structure damage and contents losses (including any related to site-specific analysis). The Asset Inventory and Development section herein describes the information used to develop the two datasets and any action necessary to reconcile potential inconsistencies.

2.1 Building Information

The building information dataset provides building-level data on existing development in Boston, allowing analysts to reference structure location, type, square footage, building use, and other information pertinent to the Vulnerability Assessment. Building information data developed for the Vulnerability Assessment consists of two datasets: CRB Building Footprints and the CRB General Building Stock. The CRB Building Footprints dataset is a polygon file, and contains limited structure information; the CRB General Building Stock is a point file, with points derived from building footprint centroids, and has more structure information required to complete the exposure and consequence analyses described in the Property, People, and Economy sections below. Refer to Table 6 and Table 7 for a list and short description of attributes associated with each dataset.

Analysts created the CRB Building Footprints dataset first, which is comprised of a variety of sources, developed separate of each other and with varying levels of accuracy. The CRB team recognizes this as a limitation of this Vulnerability Assessment, and recommends future assessments continue to review and expand upon building information data so Boston may have a complete and accurate building dataset. Refer to the **Data Integrity and Fidelity, as well as Quality Assurance and Quality Control Evaluations** section within this report for additional limitations associated with the CRB asset inventory.

TABLE 3. DATASETS USED TO COMPILE BUILDING INFORMATION DATA

Dataset	Analysis Use
City of Boston Building Footprints (2012)	Primary dataset for building footprint and structure type. Includes building height. All footprints within this dataset remain in the CRB Building Footprint dataset.
MassGIS Building Footprints (2011-2012)	Supplement City of Boston Building Footprints with additional structures with footprints greater than 1,000 square feet.[3]
Boston Redevelopment Authority Development Pipeline Data (Spring 2016)	Enhance City of Boston Building Footprints with structures built after 2012 that did not already exist in the City dataset.
Boston Redevelopment Authority New Buildings CAD File (Spring 2016)	Provide building footprints for Development Pipeline data added to the general building stock.
City of Boston Property Tax Assessing Data (Spring 2016)	Source of structure use (PTYPE) and real estate property value attributes.
Bing Aerial Imagery	Used to screen data for current conditions.
Google Aerial Imagery	Used to screen data for current conditions.
Google Street View	Used to screen data for current conditions and estimate building height of buildings added to the primary dataset.
2009 LiDAR Topography	Provide structure grade elevation (refer to the **Building Elevation** section for more detail on why the most recent LiDAR data was not used for the analysis).

[3] MassGIS Building Footprint data does not include structure type; spot evaluation of a number of the buildings less than 1,000 square feet indicated that most of the structures were outbuildings or awnings.

2.1.1 Building Footprints

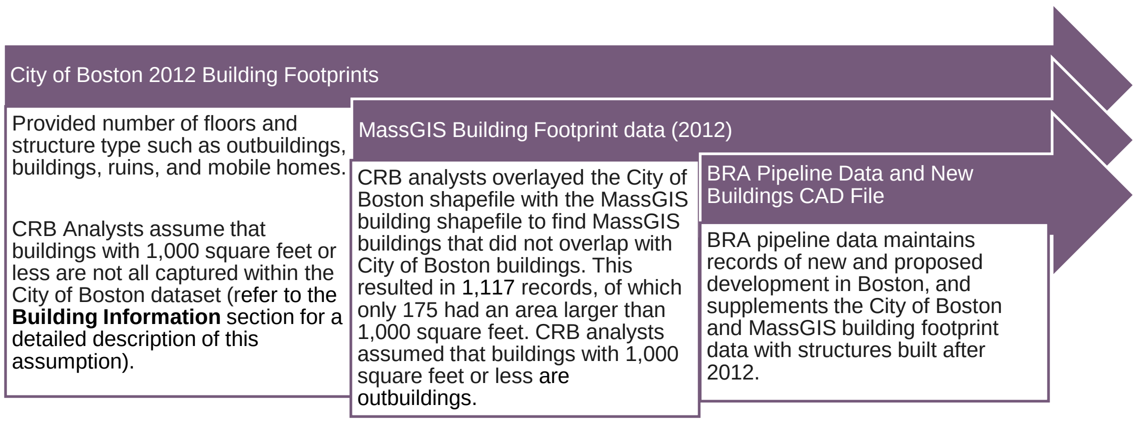

FIGURE 1. CRB BUILDING FOOTPRINT DATA PROCESS OVERVIEW

The primary data source for the CRB Building Footprint data is the City of Boston 2012 Building Footprints, which provided the number of floors and structure type such as buildings, building foundation, building under construction, outbuilding, overhead walkway joining buildings, ruins, and mobile homes. Due to the age of the dataset and discrepancies found upon review of other data sources, the MassGIS Building Footprints Data (2011-2012) and the Boston Redevelopment Authority (BRA) New Buildings CAD file and Development Pipeline Data, supplement the City of Boston 2012 Building Footprint dataset for the CRB Vulnerability Assessment.

Many additional buildings exist in the MassGIS Building Footprint data that are not present in the original City of Boston Building Footprint dataset. To identify potential additional buildings to add to the CRB Building Footprint dataset, CRB analysts overlaid the MassGIS building shapefile with the City buildings shapefile in GIS, and performed a selection analysis to find MassGIS buildings that did not overlap with the City of Boston buildings. This resulted in 1,117 records, of which only 175 had an area larger than 1,000 square feet. MassGIS Building Footprint data does not include structure type; spot evaluation of a number of the buildings less than 1,000 square feet indicated that many of the structures were outbuildings or awnings, rather than adjacent structures or row houses. Due to time constraints, analysts used the results of the spot evaluation to assume that any buildings less than 1,000 square feet may be considered an outbuilding such as a garage or a shed. This assumption may exclude small single-family residential structures that are not captured in the City of Boston Building Footprint dataset from the CRB Building Footprints Dataset. Nevertheless, QAQC of the data revealed that this might be a very limited concern.

CRB analysts conducted additional comparisons between the MassGIS and City of Boston building data to assess the accuracy of the City of Boston building data. A building and parcel analysis was conducted to identify parcels for which the area covered by buildings varied by more than 15 percent between the two datasets. This threshold assumes that differences less than 15 percent were likely to have been due to differences in building footprint for identical buildings, rather than representing additional buildings. Note that the largest changes in building footprint (either gained or lost) were associated with misclassifications of paved areas as buildings in the MassGIS dataset or missed rooftops between higher buildings that the dataset appeared to assume were not buildings. This provides a strong indication that the City of Boston buildings dataset is more accurate and the best data source for the analysis.

The BRA's Development Pipeline Data, which maintains documentation of new and proposed development in Boston, supplemented the City of Boston and MassGIS building footprint data with structures built after 2012. Projects that the Development Pipeline data indicated as complete or under construction as of 2012 were screened for inclusion in the general building stock as "recent additions." CRB analysts compared those records with City of Boston building footprint data, and those with existing records in the footprint data were not added to the CRB Building Footprint data to avoid duplication. Also excluded from the CRB Building Footprint data were pipeline points representing non-building improvements (e.g. parks); the remaining "recent addition" pipeline points were compared to the City of Boston Assessing data. If the Assessing data indicated no assessed value or had no record, analysts considered the property unimproved.[4] Building footprints for properties with assessed values were sourced from the BRA's New Buildings CAD file, or digitized based off aerial imagery. All building footprint parcels were assigned a unique ID, called the CRBID, for ease of identification, cross-referencing, and quality control. Original identification numbers and sources of buildings are maintained in the CRB Building Footprint data to assist the City in identifying original data sources.

[4] Google Street View was used to screen any questionable properties for existing conditions.

2.1.2 Structure Information

Structure Attributes Available in Boston Datasets

- Square Footage
- Number of Stories
- Building elevation
- Building Use
- Real Estate Property Value

In order to assess the potential for structural damage and other impacts related to coastal and riverine flooding, analysts must build upon the building footprint data to understand structure square footage, number of stories, building elevation, real estate market value, building use, and other attributes, some of which must be developed or calculated in the absence of available existing data. This set of structure information is referred to as the general building stock throughout the remainder of this report. When possible, these attributes are sourced from a singular dataset to promote data consistency. Deviations from this approach are detailed below.

Square footage

The City of Boston Building Footprint dataset did not contain structure square footage in its attribute data. Rather than supplement structure square footage data from other datasets, CRB analysts calculated the area of the building footprint polygons using the "Calculate Geometry" tool in ArcGIS. The area of the building footprint is considered the square footage per floor for the remainder of this analysis.

Number of stories

The number of stories for a building is provided in the City's Assessing data; however, Assessing records are based on ownership within a parcel, rather than by building. Thus, there may be multiple records for one building, particularly condominiums, each one reporting a different number of floors. Nevertheless, the City of Boston Building Footprint dataset essentially contains the height of the building (ground level). CRB analysts divided this building height by 10 feet, and rounded to the nearest whole number, to determine the approximate number of floors that would exist within each building. This is a rough, yet necessary, approximation of building height because structure height is not always uniform from foundation to rooftop.[5]

Structures added to the general building stock as a supplement to the City of Boston Building Footprint data that did not have number of stories or structure height information available, were assumed to be

[5] This could lead to some data discrepancies for multi-story structures that change shape as they rise, but the implications of this are expected to be minimal; the consequence analysis mostly considers impacts on the lowest floors of the structure. Nevertheless, square footage for up to ten floors for urban high rise structures is considered due to processes required to use the depth damage functions. Please see **Section 3.4 Structure Damage and Contents Losses** for more on this.

single-story structures if the building area was between 1,000 and 2,000 square feet. CRB analysts used aerial imagery and Google Streetview to estimate building height for polygons with footprints larger than 2,000 square feet, assuming a general floor height of 10 feet. Analysts employed the latter approach to estimate building height for approximately 200 structures. To determine the total structure square footage, analysts multiplied the square footage per floor by the structure's number of stories.

Building elevation

Structure grade elevation is an essential field used to estimate the approximate flood depth within structures for the various flood scenarios evaluated. To determine the structure grade elevation, CRB analysts extracted the average elevation within a structure footprint from the 2009 LiDAR topography dataset. This approach does not identify the presence of basements, although basement information is not necessary for the exposure and consequence analysis (refer to the **Structure Damage and Contents Loss Exposure Analysis** for more detail). More recent LiDAR data exists (2012), but analysts chose to use the 2009 LiDAR dataset to maintain consistency with the data used to develop depth grids for coastal and riverine flooding.

Building use

Various building uses, or occupancies, are affected differently by flood hazard. As such, building use is a critical field to understand potential flood impacts. The Boston Assessing data provides the structure use for each record within a parcel, referred to as a PTYPE; records are based on property use and ownership within a parcel, and are not directly correlated to building footprints. In order to attach an assessing record's PTYPE to a building footprint, three datasets were overlaid in ArcGIS: Boston parcel geometry, Boston Assessing records, and the CRB building footprint dataset (the results of the building footprint analysis and reconciliation described above). CRB analysts used the following approach to assign PTYPEs to a building:

1. Spatially join parcel data to assessing data, so that each assessing record has a parcel ID and each parcel has a group of assessing records. This is important for the case of condominiums and other parcels and structures with multiple assessing records;
2. Spatially join assessing records to building footprints so each structure has a parcel ID and PTYPE

Building footprints that did not have associated assessing records after this process were screened using aerial imagery and Google Streetview to determine property use. Structures with multiple assessing records of different PTYPEs, one of which was residential, were reassigned as mixed-use buildings.

PTYPE Categories

CRB analysts assigned categories to PTYPES to assist in the exposure and consequence analysis. Two category frameworks exist: a detailed category and a quick category used throughout the Vulnerability Assessment to facilitate reporting. Table 4 provides the PTYPE mapping used in the CRB Vulnerability Assessment. The Property Class Descriptions are based on the property classification system used by the Boston Assessing Department;[6] buildings with PTYPES not found on the Boston Assessing Department list were reviewed in GIS and in Google Streetview, and assigned descriptions based on the Massachusetts property type classification codes.[7] All three use categories are retained in the dataset for future adjustment, as needed.

TABLE 4. PTYPE CATEGORIES

PTYPES	Property Class Description	Detailed Category	Quick Category
Multiple Use Property			
10	Condo Multi-Use	Mixed Use	Mixed Use
012	Res /Open Space Use	Mixed Use	Mixed Use
13	Res /Commercial Use	Mixed Use	Mixed Use
19	Res /Exempt Use	Mixed Use	Mixed Use
25	Rc: One Res Unit	Mixed Use	Mixed Use
26	Rc: Two Res Units	Mixed Use	Mixed Use
27	Rc: Three Res Units	Mixed Use	Mixed Use
31	Com /Res Multi-Use	Mixed Use	Mixed Use
Residential Property			
101	Single Fam Dwelling	Residential - 1-3 Family	Residential
102	Residential Condo	Residential - Multifamily	Residential
103	Mobile Home	Residential - 1-3 Family	Residential
104	Two-Fam Dwelling	Residential - 1-3 Family	Residential
105	Three-Fam Dwelling	Residential - 1-3 Family	Residential
106	Res Ancill Improvemt	Residential - Other	Residential
107	Other Residential	Residential - Other	Residential

[6] Boston Assessing Department. Massachusetts Property Classification System Occupancy Codes. [web page] located at: https://www.cityofboston.gov/images_documents/MA_OCCcodes_tcm3-16189.pdf.

[7] Massachusetts Department of Revenue. Property Type Classification Codes. [web page] located at: http://www.mass.gov/dor/docs/dls/bla/classificationcodebook.pdf.

PTYPES	Property Class Description	Detailed Category	Quick Category
108	Condo Parking (Res)	Parking and Storage	Residential
109	Multiple Bldgs/1 Lot	Residential - 1-3 Family	Residential
110	Condo Storage (Res)	Parking and Storage	Parking and Storage
Apartment Property			
111	Apt 4-6 Units	Residential - Multifamily	Residential
112	Apt 7-30 Units	Residential - Multifamily	Residential
113	Apt 31-99 Units	Residential - Multifamily	Residential
114	Apt 100+ Units	Residential - High Occupancy	Residential
115	Co-Op Apartment	Residential - Multifamily	Residential
116	Res Parking Garage	Parking and Storage	Parking and Storage
117	Day Care Use	Child Care Facility	Essential Services
118	Elderly Home	Residential - Clinic	Residential
119	Res Parking Lot	Parking and Storage	Parking and Storage
120	Multi-Use	Mixed Use	Mixed Use
121	Rooming House	Residential - Multifamily	Residential
122	Fraternity House	Residential - Multifamily	Residential
123	Residence Hall	Residential - High Occupancy	Residential
124	Dorms Or Group Housing	Residential - High Occupancy	Residential
125	Subsd Housing S- 8	Residential - Subsidized Housing	Residential
126	Subsd Housing S-231D	Residential - Subsidized Housing	Residential
127	Subsd Housing S-202	Residential - Subsidized Housing	Residential
130	Residential Land	Residential - Other	Residential
131	Res Land (Secondary)	Residential - Other	Residential
132	Res Land (Unusable)	Residential - Other	Residential
140	Child Care Facility	Child Care Facility	Essential Services
150	Apt : Studio	Residential - Multifamily	Residential
151	Apt : 1 Bedroom Unit	Residential - Multifamily	Residential
152	Apt : 2 Bedroom Unit	Residential - Multifamily	Residential
153	Apt : 3 Bedroom Unit	Residential - Multifamily	Residential
154	Apt : 4 Bedroom Unit	Residential - Multifamily	Residential
Commercial Property			

PTYPES	Property Class Description	Detailed Category	Quick Category
300	Hotel	High Occupancy (NonResidential)	Commercial
301	Motel	High Occupancy (NonResidential)	Commercial
302	Inn, Resort, B & B	High Occupancy (NonResidential)	Commercial
303	Priv City Club	High Occupancy (NonResidential)	Commercial
304	Nursing /Conv Home	Residential - Clinic	Residential
305	Hospital: Private /Taxable	Hospital/Medical	Essential Services
306	Laboratory	Hospital/Medical	Essential Services
307	Veterinary Hospital	Hospital/Medical	Essential Services
309	Med Clinic Outpatient	Hospital/Medical	Essential Services
310	Laundry Operation	Commercial - Service Based	Commercial
311	Laundromat /Cleaner	Commercial - Service Based	Commercial
312	Mini-Storage Whse	Parking and Storage	Parking and Storage
313	Lumber Yard Storage	Industrial	Industrial
314	Truck Terminal	Transportation	Transportation
315	Piers / Dock	Transportation	Transportation
316	Warehouse / Distributi	Industrial	Industrial
317	Storage Whse / Garage	Parking and Storage	Parking and Storage
318	Cold Storage Whse	Parking and Storage	Parking and Storage
319	Strip Center /Stores	Commercial - Retail	Commercial
320	Retail /Whsl /Service	Commercial - Retail	Commercial
321	Discount Store	Commercial - Retail	Commercial
322	Department Store / Mal	Commercial - Retail	Commercial
323	Shopping Center	Commercial - Retail	Commercial
324	Supermarket	Food Supply	Food Supply
325	Retail Store Detached	Commercial - Retail	Commercial
326	Restrant /Service	Commercial - Service Based	Commercial
327	Restrant /Lounge	Commercial - Service Based	Commercial
328	Fast Food Restaurant	Commercial - Service Based	Commercial
329	Bar /Tavern /Pub	Commercial - Service Based	Commercial
330	Showroom (Auto)	Commercial - Retail	Commercial
331	Auto Supply /Service	Commercial - Service Based	Commercial

PTYPES	Property Class Description	Detailed Category	Quick Category
332	Repair /Serv Garage	Commercial - Service Based	Commercial
333	Self-Serv Station	Commercial - Service Based	Commercial
334	Service Center / Retail	Commercial - Service Based	Commercial
335	Car Wash: Automatic	Commercial - Service Based	Commercial
336	Com Parking Garage	Parking and Storage	Parking and Storage
337	Parking Lot	Parking and Storage	Parking and Storage
338	Subterranean Garage	Parking and Storage	Parking and Storage
339	Car Wash: Self-Service	Commercial - Service Based	Commercial
340	Office (Attached)	Commercial - Office	Commercial
341	Bank Building	Commercial - Office	Commercial
342	Medical Office	Hospital/Medical	Essential Services
343	Office 1-2 Story	Commercial - Office	Commercial
344	Office 3-9 Story	Commercial - Office	Commercial
345	Office : Class B	Commercial - Office	Commercial
346	Office : Class B+	Commercial - Office	Commercial
347	Office : Class A-	Commercial - Office	Commercial
348	Office Tower: Class A	High Occupancy (NonResidential)	Commercial
350	Postal Service	General Government	General Government
351	Training /Priv Educ	Education	Education
352	Day Care Use (Com Bldg)	Child Care Facility	Essential Services
353	Social Club	Recreational	Recreational
354	Mausoleum	Cultural	Cultural/Religious
355	Funeral Home	Commercial - Service Based	Commercial
356	Comm Condo	Commercial - Service Based	Commercial
357	Retail Condo	Commercial - Retail	Commercial
358	Office Condo	Commercial - Office	Commercial
359	Condo Parking (Com)	Parking and Storage	Parking and Storage
360	Museum, Gallery	Cultural	Cultural/Religious
361	Night Club	Recreational	Recreational
362	Movie Theater	High Occupancy (NonResidential)	Recreational
363	Drive-In Theater	Recreational	Recreational

PTYPES	Property Class Description	Detailed Category	Quick Category
364	Stage Theater	Recreational	Recreational
365	Auditorium/Sport Ctr	High Occupancy (NonResidential)	Recreational
366	Fieldhouse /Track	Recreational	Recreational
367	Race Track	High Occupancy (NonResidential)	Recreational
368	Fairground, Park	Recreational	Recreational
369	Artist Studio	Commercial - Service Based	Commercial
370	Bowling Alley	Recreational	Recreational
371	Arena: Ice Skating	Recreational	Recreational
372	Arena: Roller Skating	Recreational	Recreational
373	Swimming Pool -Enclosed	Recreational	Recreational
374	Health Spa /Club	Commercial - Service Based	Commercial
375	Tennis/ Racquet Club	Recreational	Recreational
376	Gym /Athletic Facility	Recreational	Recreational
377	Recreation Bldg	Recreational	Recreational
378	Private Schools/Tutoring Centers	Education	Education
379	Churches	Religious	Cultural/Religious
380	Golf Course	Recreational	Recreational
381	Tennis Court(S)	Recreational	Recreational
382	Stable, Kennel	Recreational	Recreational
383	Swimming Pool -Outdoor	Recreational	Recreational
384	Boat House / Marina	Industrial	Industrial
385	Taxable Bldg Only	Recreational	Recreational
386	Campground Facility	Recreational	Recreational
387	Pay Parking Lot	Parking and Storage	Parking and Storage
388	Air Rights Property	Transportation	Transportation
389	Bldg: Chap 61 A Land	Agriculture	Agriculture
390	Commercial Land	Commercial - Other	Commercial
391	Com Land (Secondary)	Commercial - Other	Commercial
392	Com Land (Unusable)	Commercial - Other	Commercial
393	Com Underwater Land	Commercial - Other	Commercial
394	Utility Bldg /Shed	Other	Other

PTYPES	Property Class Description	Detailed Category	Quick Category
395	Air Freight Terminal	Transportation	Transportation
396	Hangar: Storage, Maint	Transportation	Transportation
397	Bus / Rail Terminal	Transportation	Transportation
398	Airport Terminal	Transportation	Transportation
399	Com Greenhouse	Commercial - Retail	Commercial
Industrial Property			
400	Old Manufacturing	Industrial	Industrial
401	Old Industrial Whse	Industrial	Industrial
402	Office: Industrial Use	Industrial	Industrial
403	New Manufacturing	Industrial	Industrial
404	Light Mfg / R & D	Industrial	Industrial
405	Industrial Loft	Industrial	Industrial
406	Computer Equip Bldg	Industrial	Industrial
407	Machine Shop (Small)	Industrial	Industrial
408	Newspaper Plant	Industrial	Industrial
410	Mining, Quarrying	Industrial	Industrial
412	Metal Processing	Industrial	Industrial
413	Auto Salvage Yard	Industrial	Industrial
414	Food Process Plant	Food Supply	Food Supply
415	Bottling Plant	Food Supply	Food Supply
416	Cannery	Food Supply	Food Supply
417	Dairy	Agriculture	Agriculture
420	Tanks: Above Ground	Utility - Other	Utility
421	Tanks: Under Ground	Utility - Other	Utility
422	Elec Power Plant	Utility - Electric	Utility
423	Elec Trans R O W	Utility - Electric	Utility
424	Elec Substation	Utility - Electric	Utility
425	Gas Manufactr Plant	Utility - Gas	Utility
426	Gas Pipeline R O W	Utility - Gas	Utility
427	Gas Storage	Utility - Gas	Utility
428	Gas Pressure Station	Utility - Gas	Utility

PTYPES	Property Class Description	Detailed Category	Quick Category
430	Teleph Exchg Station	Telecommunications and IT	Telecommunications and IT
431	Teleph Relay Tower	Telecommunications and IT	Telecommunications and IT
432	Cable T V Facility	Telecommunications and IT	Telecommunications and IT
433	Radio /Tv Trans Facil	Telecommunications and IT	Telecommunications and IT
435	Radio /Tv Studio	Telecommunications and IT	Telecommunications and IT
436	Studio /Remote Contr	Telecommunications and IT	Telecommunications and IT
440	Industrial Land	Industrial	Industrial
441	Ind Land (Secondary)	Industrial	Industrial
442	Ind Land (Unusable)	Industrial	Industrial
445	Railroad Prop	Transportation	Transportation
446	Water /Sewer Utility	Utility - Water and Sewer	Utility
450	Industrial Condo	Industrial	Industrial
465	Com Billboard	Industrial	Industrial
Exempt Ownership			
900	U.S. Government	General Government	General Government
901	Commonwealth Of Mass	General Government	General Government
902	City of Boston	General Government	General Government
903	Bost Redevelop Auth	General Government	General Government
904	Priv School /College	University	Education/University
905	Charitable Organiztn	Cultural	Cultural/Religious
906	Religious Organizatn	Religious	Cultural/Religious
907	121-A Property	Residential - Multifamily	Residential
908	Boston Housing Authority[8]	Residential - Subsidized Housing	Residential
910	Mass Dept Environment Mgmt	General Government	General Government
912	Mass Dept Of Youth Services	General Government	General Government
914	Mass Dept Of Mental Health	General Government	General Government
915	Metro Dist Com (Mdc) Land	General Government	General Government
917	Mass Dept Education (College)	University	Education/University
918	Mass Environment Protection	General Government	General Government
920	Mass Environment Mgmt	General Government	General Government

[8] These assets were visually confirmed using Google Earth and Google Street View, as well as local knowledge.

PTYPES	Property Class Description	Detailed Category	Quick Category
921	Mass Environmt Protection	General Government	General Government
922	Mass Corrections / Police	Essential Services	Essential Services
923	Mass Dept Of Public Health	General Government	General Government
924	Mass Highway Dept	General Government	General Government
925	Metropolitan Dist Com (Mdc)	General Government	General Government
926	Mass Dept Justice /Judiciary	General Government	General Government
927	Mass Dept Education (College)	University	Education/University
928	Mass Div Capital Asset Mgmt	General Government	General Government
929	Mass : Other Property	General Government	General Government
937	Dorms, Student Housing	Residential - High Occupancy	Residential
941	Symphony Hall	Recreational	Recreational
942	College (Academic)	University	Education/University
945	School	Education	Education
947	Recreational School Use	Education	Education
950	Retail Condo: Exempt	Commercial - Retail	Commercial
951	Priv School /College	University	Education/University
952	Priv School /College	University	Education/University
953	Health Center	Hospital/Medical	Essential Services
954	Gov'T Office Bldg	General Government	General Government
955	Harvard Medical	Hospital/Medical	Essential Services
957	City Of Boston	General Government	General Government
958	Rehabilitation Centers	Hospital/Medical	Essential Services
959	Women's Care Centers	Hospital/Medical	Essential Services
960	Office Condo: Exempt	Commercial - Office	Commercial
962	Port Authority Property	Transportation	Transportation
963	Seafood Market	Food Supply	Food Supply
965	Gov'T Office Bldg	General Government	General Government
966	Piers / Dock	Transportation	Transportation
968	School	Education	Education
969	Piers / Dock	Transportation	Transportation
970	Church, Synagogue	Religious	Cultural/Religious

PTYPES	Property Class Description	Detailed Category	Quick Category
971	Rectory, Convent	Religious	Cultural/Religious
972	Correctional Bldg	High Occupancy (NonResidential)	Essential Services
973	Administrative Bldg	General Government	General Government
974	Fire Station	Essential Services	Essential Services
975	Police Station	Essential Services	Essential Services
976	School	Education	Education
977	College (Academic)	University	Education/University
978	Library	Cultural	Cultural/Religious
979	Hospital (Exempt)	Hospital/Medical	Essential Services
980	Water Treatmt Plant	Utility - Water and Sewer	Utility
981	Incineration Plant	Utility - Steam	Utility
982	Armory (Military)	Essential Services	Essential Services
983	Cemetery	Cultural	Cultural/Religious
984	Public Beach	Recreational	Recreational
985	Improved Municipal Or Public Safety, Other City Or Town	Essential Services	Essential Services
986	Local/State Transportation	Transportation	Transportation
987	Public Housing	Residential - Subsidized Housing	Residential
990	Logan Airport	Logan Airport	Transportation
988	Convention Center	Cultural	Cultural/Religious

Property market value (land plus improvements)

Property market value is an important consideration when looking at exposure of buildings to recurrent flooding. Real estate market values can decrease significantly with increased perception of flood risk, which may not only affect the cost of ownership of exposed buildings in the future, but also affect their desirability. The Boston Assessing data contains building and land assessed values; these values are provided per record; as such, there are often multiple assessing records for both parcels and buildings and some records must be summed. Analysts employed the below approach to assign real estate property value (land plus improvements) to building footprints. Assessed value is the valuation placed on a property by a public tax assessor for the purpose of taxation; thus, property value estimates reported in the CRB exposure and consequence analysis are likely a conservative reflection of Boston's property market values. It is important to note that the laws of the State of Massachusetts require that assessing records include full market value.[9] As such, analysts used the market values as is.

1. Spatially join Assessing data to parcel data. Total assessed values are summed by parcel ID to get the total real estate market value present within a parcel; this combines condominium values into a single total value per parcel.
2. Spatially join building data (which has already been joined to the Assessing records) to parcel data. The total square footage (footprint multiplied by number of stories) is calculated per parcel. Each building within a parcel is then assigned the percentage of square footage that it contributes to the building area within a parcel. The total value of the parcel is multiplied by the building's assigned percentage to determine the value of the building. For most buildings, this value is 1, which indicates that most parcels contain only one building.

2.1.3 Data Integrity and Fidelity, as well as Quality Assurance and Quality Control Evaluations

As the general building stock is a compilation of various data sources, CRB analysts performed several quality control reviews to verify data accuracy.

QAQC of Building Polygons

Large buildings with complex rooflines, especially those with varying heights, consist of multiple polygons in the City of Boston building footprint dataset. Each building polygon is used in the exposure and consequence analysis, and while the square footage and height of each polygon would not skew the results of the quantified consequence analysis, the extra polygons may result in an overestimate of the number of buildings reported as exposed to hazards. To avoid overestimating the number of buildings exposed to coastal and riverine flooding, CRB analysts conducted a quality control review of buildings within the flood extent of the 0.1 percent annual chance event with 36 inches of sea level rise that were over 10,000 square feet and adjacent to others, and had identical PTYPEs. The focus of the review was further limited to screen structures within the General Government, Essential Services,

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[9] According to Massachusetts General Laws, Chapter 59, Section 38, "*The Assessing Department is statutorily required to assess all property at its full and fair cash value as of January 1 of each year (Massachusetts General Laws, Chapter 59, Section 38). The assessed value for the Fiscal Year 2016 tax bill represents the fair cash value of property as of January 1, 2015.*" See *City of Boston Property Tax Facts and Figures: Fiscal Year 2016* for more information, located at:
https://www.cityofboston.gov/images_documents/FY2016%20Facts%20%26%20Figures_tcm3-52871.pdf

Industrial, and Hospital/Medical building categories, as CRB analysts assumed that these types of uses are likely to be located within large buildings with complex rooflines. This limited the review to approximately 400 structures. Structures that met the aforementioned criteria were provided modified CRBIDs, and the parts were dissolved into a single polygon. A representative number of floors was determined based on the following calculation:

$$[Sum\ of\ (Footprint\ of\ each\ Polygon * Number\ of\ Floors\ of\ each\ Polygon)]/$$
$$[Sum\ of\ Footprint\ Area] = Number\ of\ Floors$$

Once the buildings were dissolved, the modified building dataset was re-merged with the general building stock based on the CRBBldgID.

QAQC of Elevations and PTYPEs

CRB analysts reviewed elevations of a sample set of structures (approximately 150 structures) to ensure accuracy of average structure grade elevations pulled from LiDAR and accuracy of building occupancy labels. The evaluation was performed using Google Earth and Streetview. CRB analysts conducted the review by cross-referencing the ground elevation posted by Google Earth at a site, and used Streetview to gauge the height of the structure's first floor off the ground. Due to differences in the datum of the two elevation datasets, and to account for rounding, elevation differences that were less than two feet were considered appropriate. This review also allowed analysts to confirm PTYPE assignments for a sample of structures. Elevations and PTYPEs were manually adjusted in the general building stock as needed.

CRB analysts performed a running quality control evaluation of elevations and PTYPEs as described above throughout the exposure and consequence analysis. Each neighborhood's top 15 structures with the highest estimated annualized structure damage and contents loss values were reviewed to ensure accuracy. As changes were made, any structures that moved into the top 15 were additionally reviewed. This resulted in a manual review of the occupancies of several hundred structures. More on this process is described within the **Structure Damage and Contents Loss Consequence Analysis** section below.

2.1.4 Building Information Assumptions and Limitations

The CRB team recognizes the approach to construct the full general building stock is not without limitations. Assumptions made in developing the general building stock and associated data limitations include:

- When adding MassGIS Building Footprint data to the City of Boston Building Footprint data, CRB analysts assumed that any new structures less than 1,000 square feet to be an outbuilding such as a garage or shed and were not added (though no structures less than 1,000 square feet were removed from the City of Boston dataset). A threshold had to be set due to the absence of occupancy data in this supplemental dataset, and the time that would be required to manually review and confirm the uses and occupancies of all structures. This structure size was selected and confirmed through an analysis of a sample of structures using Google Streetview. As MassGIS data did not include building height, structures from this dataset between 1,000 and 2,000 square feet were assumed to be single-story buildings. This is based on the fact that the average footprint for buildings with two stories was found to be around 2,000 square feet (determined by the City of Boston Building Footprint data), as confirmed through Google Streetview using a sample of structures. CRB analysts used aerial imagery and Google Streetview to estimate building height for polygons with footprints larger than 2,000 square feet, assuming a floor height of 10 feet.
- Many residences in Boston are split-level structures, and have living space that sits below grade. The approach to estimate structure grade elevation takes an average of the highest and lowest grade elevation within the footprint of the building. Thus, many structures that are split-level or have basements will have conservatively low damage results in the consequence analysis.
- Assessing records are assumed accurate and up to date. Buildings that had multiple, and divergent, assessing records with various PTYPEs, one of which was residential, assigned to its footprint were reassigned PTYPEs to indicate the structure is mixed-use. Any structures with improperly assigned PTYPES identified through the quality control review were manually modified in the general building stock.
- Due to the number of buildings and the number of structure characteristics and occupancy types within the CRB general building stock dataset, as well as available time and budget, CRB analysts were unable to QAQC all data. As such, analysts prioritized a review of structures within the 0.1 percent annual chance inundation area for 36 inches of sea level rise, which is the furthest extent of the CRB study area. Therefore, the fidelity and integrity of structure information outside of that flood extent has not been verified, and must be considered when performing future analyses, as well as when considering results of the stormwater exposure analysis.[10] Furthermore, QAQC of the CRB general building stock within the 0.1 percent annual chance flood extents with 36 inches of sea level rise prioritized structures with the largest building footprints, due to the

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[10] Site-specific assets found to be exposed to stormwater flooding were also reviewed for accuracy; however, this review was limited due to the number of site-specific assets exposed.

potential for such large structures to dramatically affect overall results. Due to the scale of corrections that were required, CRB analysts assume that errors still exist within the general building stock, especially for smaller structures and those outside of the CRB Vulnerability Assessment coastal and riverine flooding study area.

2.2 Site-Specific Asset Information

CRB analysts gathered site-specific information for infrastructure assets and systems to assess exposure to hazards. Infrastructure assets and systems considered range from critical facilities, such as water treatment facilities and generating plants, to transportation infrastructure, to essential facilities such as hospitals and emergency operations centers, to public facilities such as schools and civic structures. The CRB site-specific asset information data collection process consisted of two major efforts: first, gathering all available and appropriate public data, and second, collecting information from individual agencies and organizations, as well as the IAG. CRB analysts cross-referenced site-specific information received with the general building stock, to serve as a secondary quality control review for structure use, and modified information in the general building stock as appropriate.

2.2.1 Asset Data Collection

CRB analysts gathered publicly available data from a variety of sources in ArcGIS format, most notably BostonMaps,[11] MassDOT,[12] and MassGIS.[13] CRB partners, including Sasaki, Boston Department of Innovation and Technology (DoIT), the Boston Redevelopment Authority (BRA), and the Boston Regional Intelligence Center (BRIC), also submitted robust datasets for review and inclusion in the CRB asset inventory. CRB analysts compiled all polygon files into a geodatabase, and created six general categories for which to organize the data: environmental systems, transportation systems, utility systems,[14] public facilities, vulnerable populations, health and safety, education, and other. Analysts compiled point data into one shapefile using attributes presented in Table 8, for which certain attributes or sources may be queried. Data received from public sources and CRB partners formed the basis of the site-specific asset inventory. A total list of site-specific data gathered and data sources is provided in Table 5.

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11 http://boston.maps.arcgis.com/home/index.html

12 http://www.massdot.state.ma.us/planning/Main/MapsDataandReports/Data/GISData.aspx

13 http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/layerlist.html

14 Utility systems include water and wastewater and power and gas systems.

To collect information from the IAG, analysts asked members to complete an asset inventory template in Microsoft excel format, and requested any GIS data files applicable to the data request. The template is intended to collect the locations of important assets that are owned or maintained by IAG members, in addition to site-specific information that would allow CRB analysts to evaluate asset vulnerabilities to flood risk and other hazards during future evaluation refinements. Table 8 provides specific attributes requested in the asset inventory template.

Many agencies submitted existing datasets for CRB analysts to pull out necessary information and populate the asset inventory template. Due to privacy and security concerns, utilities and service companies often opted to conduct exposure and consequence analyses on their own, following guidance and using hazard data provided by CRB, and share the results in a qualitative manner with the CRB team. Analysts processed data submitted by IAG members in a manner similar to that described for the public and CRB partner datasets, and built upon the inventory developed for public and CRB partner data.

TABLE 5. DATA COLLECTED[15]

Dataset	Source	Dataset and Category
Airports	MassDOT	Point - Transportation
All Bridges	IAG - OEM	Point - Transportation
Aqueducts	MassGIS	Point - Utility
Areas of Critical Environment Concern	MassGIS	Polygon - Environmental Systems
Article 80 Buildings	IAG - BRA	Point - Other
Bike Lanes and Paths	MassDOT	Polyline - Transportation
Boston City Boundary	OpenData	Polyline - Other
Boston Public Schools	IAG - BPS	Point - Public Facilities
Boston Public Schools	BRA Article 80 Pipeline	Point - Public Facilities
Boston Redevelopment Authority Facilities	Assessor Data	Point - Other
Boston University	Assessor Data	Point - Education
Boston University	BRA Article 80 Pipeline	Point - Education
Bus Routes – MBTA	MassGIS - MBTA	Polyline - Transportation
Bus Stops – MBTA	MassGIS - MBTA	Point - Transportation
BWSC Facilities	Assessor Data	Point - Utilities
BWSC Facilities	BRA Article 80 Pipeline	Point - Utilities

[15] Does not include a list of data collected under Non-Disclosure Agreements.

Dataset	Source	Dataset and Category
BWSC Offices	IAG - BWSC	Point - Utilities
Census Block Groups	MassGIS	Polygon - Other
Census Blocks	MassGIS	Polygon - Other
Census Tracts	MassGIS	Polygon - Other
Central Artery and Tunnel System Facilities	MassDOT	Point - Transportation
Child Care Centers	IAG - OEM	Point - Vulnerable Populations
Colleges and Universities	MassGIS	Point – Education
Colleges and Universities	Assessor Data	Point – Education
Colleges and Universities	BRA Article 80 Pipeline	Point – Education
Community Centers - BCYF	IAG - DoIT - OEM	Point - Health and Safety
Community Health Centers	MassGIS	Point - Health and Safety
Community Health Centers	Assessor Data	Point - Health and Safety
Community Health Centers	BRA Article 80 Pipeline	Point - Health and Safety
Corner Stores	Sasaki	Point - Other
Cultural Institutions	IAG - DoIT - OEM	Point - Other
Dams	MassGIS	Point - Utilities
Department of Conservation and Recreation Facilities	Assessor Data	Point - Environmental Systems
Department of Public Utilities Office	IAG - DPU	Point - Other
Department of Public Works Facilities	Assessor Data	Point - Other
Drainage - Major Basins	MassGIS	Polygon - Environmental Systems
Drainage - Mega Basins	MassGIS	Polygon - Environmental Systems
Drainage - Sub Basins	MassGIS	Polygon - Environmental Systems
Elderly Services	Assessor Data	Point - Vulnerable Populations
Elderly Services - General	IAG - DoIT - OEM	Point - Vulnerable Populations
Elderly Services - Medical	IAG - DoIT - OEM	Point - Vulnerable Populations
Elderly Services - Private Housing	IAG - DoIT - OEM	Point - Vulnerable Populations
Elderly Services - Public Housing	IAG - DoIT - OEM	Point - Vulnerable Populations
Emergency Operations Center Stations	IAG - DoIT - OEM	Point - Health and Safety
Emergency Preparedness Regional Coalitions	MassGIS	Polygon - Health and Safety

Dataset	Source	Dataset and Category
Emergency Preparedness Regions	MassGIS	Polygon - Health and Safety
EMS Districts	DoIT - PSS	Polygon - Health and Safety
EMS Regions	MassGIS	Polygon - Health and Safety
EMS Sites	IAG - DoIT - OEM	Point - Health and Safety
Environmental Justice Communities	MassGIS	Polygon - Vulnerable Populations
Evacuation Routes	BostonMaps	Polyline - Transportation
Farmers' Markets	MassGIS	Point - Other
Ferry Routes	MassDOT	Polyline - Transportation
Fire Districts	OpenData	Polygon - Health and Safety
Fire Response Zones	DoIT - BFD	Polygon - Health and Safety
Fire Sectors	DoIT - BFD	Polygon - Health and Safety
Fire Stations	MassGIS	Point - Health and Safety
Fire Stations	Assessor Data	Point - Health and Safety
Fire Subdistricts	DoIT - BFD	Polygon - Health and Safety
Food Pantries	Sasaki	Point - Vulnerable Populations
Groundwater Conservation Overlay Districts	OpenData	Polygon - Utilities
Harbor Island Facilities	IAG - NPS	Point - Environmental Systems
Harvard	Assessor Data	Point – Educational
Harvard	BRA Article 80 Pipeline	Point – Educational
Hazardous/Abandoned Buildings	IAG - OEM	Point - Environmental Systems
Historic Buildings - MHC	IAG - BLC	Point - Other
Historic District Centroids	IAG - BLC	Point - Other
Historic Landmarks	IAG - BLC	Point - Other
Hospitals	MassGIS	Point - Health and Safety
Hospitals	Assessor Data	Point - Health and Safety
Hospitals	BRA Article 80 Pipeline	Point - Health and Safety
Impervious Surfaces	OpenData	Polygon - Other
Libraries	MassGIS	Point - Other
Libraries	Assessor Data	Point - Other
Libraries	IAG - DoIT - OEM	Point - Other
Light Rail Bridges	IAG - OEM	Point - Transportation
Lighthouses	MassGIS	Point - Other

Dataset	Source	Dataset and Category
Long Term Care Residences	MassGIS	Point - Health and Safety
Long Term Care Residences	Assessor Data	Point - Health and Safety
Major Roads	MassGIS	Polyline - Transportation
Major Routes	MassGIS	Polyline - Transportation
Major Routes	MassDOT	Polyline - Transportation
Major Watersheds	MassGIS	Polygon - Environmental Systems
MassDEP Major Facilities	MassGIS	Point - Environmental Systems
MassDOT Facilities	Assessor Data	Point - Transportation
MassPort Facilities	Assessor Data	Point - Transportation
MassPort Facilities	BRA Article 80 Pipeline	Point - Transportation
MBTA Facilities	Assessor Data	Point - Transportation
MBTA Facilities	BRA Article 80 Pipeline	Point - Transportation
Medical Academic and Scientific Community (MASCO) Member	IAG - MASCO	Point - Health and Safety
MWRA Facilities	Assessor Data	Point - Utilities
National Grid Facilities	Assessor Data	Point - Utilities
National Park Services Facilities	IAG - NPS	Point - Environmental Systems
Neighborhood Emergency Centers	DoIT - MIS	Point - Health and Safety
Neighborhood Emergency Shelters	IAG - DoIT - OEM	Point - Health and Safety
Nursing Homes	IAG - DoIT - OEM	Point - Health and Safety
Oil and/or Hazardous Material Sites with Activity and Use Limitations (AUL)	MassGIS - MassDEP	Point - Environmental Systems
Parks and Open Spaces	IAG - BPRD	Polygon - Environmental Systems
Parks and Recreation Facilities	Assessor Data	Point - Environmental Systems
Partners HealthCare	Assessor Data	Point - Health and Safety
Partners HealthCare	BRA Article 80 Pipeline	Point - Health and Safety
Police Districts	OpenData	Polygon - Health and Safety
Police Facilities	Assessor Data	Point - Health and Safety
Police Facilities	BRA Article 80 Pipeline	Point - Health and Safety
Police Precincts	DoIT - BPD	Polygon - Health and Safety
Police Reporting Areas	DoIT - BPD	Polygon - Health and Safety
Police Sectors	DoIT - BPD	Polygon - Health and Safety

Dataset	Source	Dataset and Category
Police Stations	MassGIS - BRIC	Point - Health and Safety
Police Subsectors	DoIT - BPD	Polygon - Health and Safety
Ponds and Lakes	MassGIS - USGS	Polygon - Environmental Systems
Ponds and Lakes	MassGIS - MassDEP	Polygon - Environmental Systems
Prisons	MassGIS	Point - Vulnerable Populations
Prisons	Assessor Data	Point - Vulnerable Populations
Protected and Recreational Open Space	MassGIS	Polygon - Environmental Systems
Public Housing	Assessor Data	Point - Vulnerable Populations
Public Housing	BRA Article 80 Pipeline	Point - Vulnerable Populations
Public Housing	IAG - BHA	Point - Vulnerable Populations
Public Pools	MassGIS - DCR	Point - Other
Public School Districts	MassGIS - BPS	Polygon – Educational
Public School Facilities	DoIT - BPS	Polygon – Educational
Pump Stations	IAG - MWRA	Point - Utilities
Pump Stations and Headworks	IAG - MWRA	Point - Utilities
Rail – All	MassGIS	Polyline - Transportation
Rail - Commuter Lines	MassGIS	Polyline - Transportation
Rail - Rapid Transit - MBTA	MassGIS - MBTA	Polyline - Transportation
Railroad Bridges	IAG - OEM	Point - Transportation
Railroads	MassDOT	Polyline - Transportation
Rapid Transit Stations - MBTA	MassGIS - MBTA	Point -Transportation
Religious Institutions	Assessor Data	Point - Other
Religious Institutions	IAG - DoIT - OEM	Point - Other
Religious Institutions	BRA Article 80 Pipeline	Point - Other
Road Bridges	IAG - OEM	Point - Transportation
Roads	MassGIS - Census	Polyline - Transportation
Roads	MassGIS	Polyline - Transportation
Roads	MassDOT	Polyline - Transportation
Roads	MassDOT	Polyline - Transportation
Roads	MassDOT	Polyline - Transportation

Dataset	Source	Dataset and Category
Schools	MassGIS - BPS	Point - Educational
Seaports	MassDOT	Point - Transportation
Sidewalks	OpenData	Polyline - Transportation
Soil Survey	MassGIS - NRCS	Polygon - Environmental Systems
Streams and Rivers	MassGIS - USGS	Polyline - Environmental Systems
Streams and Rivers	MassGIS - MassDEP	Polyline - Environmental Systems
Tier II Sites	Boston Fire Dep.	Point – Other
Town and City Halls	MassGIS	Point - Public Facilities
Traffic Count Locations	MassDOT	Point - Transportation
Train Stations	MassGIS	Point - Transportation
Train Stations	MassDOT	Point - Transportation
Transit Terminals	MassDOT	Point - Transportation
Transmission Lines	MassGIS	Polyline - Utilities
Trees	OpenData	Point - Environmental Systems
Trustees of Public Land Facilities	Assessor Data	Point - Other
Tunnels	DoIT - MIS	Polyline - Transportation
Urban Boundaries	MassDOT	Polygon - Other
Verizon	Assessor Data	Point - Other
Water Taxi Stops	MassDOT	Point - Transportation
Water/Sewer Service Areas	MassGIS - MWRA	Polygon - Utilities
Wetland Change Areas	MassGIS - MassDEP	Polygon - Environmental Systems
Wetlands	MassGIS - MassDEP	Polygon - Environmental Systems
Zoning Districts	OpenData	Polygon - Other

2.2.2 Asset Data Reconciliation

When the initial compilation of public data and submitted IAG information was complete, CRB analysts used Boston Assessing data to gather additional assets owned by IAG members (as point data) that may not have been captured within other datasets, and to fill in data gaps existing in the asset template. Due to the number of assets acquired from public datasets, IAG members, and Boston assessing information, analysts focused on reconciling assets located within the flood extent for the 0.1 percent annual chance event with 36 inches of sea level rise; the largest coastal and riverine flood extents considered within the Vulnerability Assessment. A number of site-specific assets exposed to stormwater flooding were also reconciled during the stormwater exposure analysis. Duplicates were removed from the dataset after ensuring that all relevant information for an asset was retained. Then, each IAG member was presented with data relevant to their organization for review to confirm the accuracy and reliability of asset data. IAG members were given multiple opportunities to confirm that the data pulled was correct: at a workshop held on April 12th to present the status of data collection, and in individual follow up conversations and through email correspondence with each participant. The response rate of the data review was limited. As such, and in an effort to limit potentially over-estimating exposure of important infrastructure assets, data gathered from the Assessing data that IAG members did not confirm as special assets or that analysts could not confirm through an aerial analysis were not included in the CRB site-specific asset inventory exposure analysis. These assets were, however, included in the structure exposure and consequence analysis according to the data available in the assessing records. In order to facilitate completion of the inventory for future evaluations, this unconfirmed data has been included in the site-specific asset inventory, listed as "unconfirmed" in the asset attributes.

Once reconciliation was complete, CRB analysts compiled all site-specific asset data provided in point files into a single standardized shapefile, with attributes as listed in Table 8. This template was then joined with Boston Assessing data based on spatial location to determine the parcel ID, approximate date built, approximate date of last significant renovation, and assessed property value (land and improvements).[16]

2.2.3 Asset Data Assumptions and Limitations

- Similar to the building stock, due to the amount of site-specific asset information collected throughout Boston coupled with budget and schedule constraints, CRB analysts prioritized assets for QAQC located within the 0.1 percent chance inundation area for 36 inches of sea level rise, and prioritized certain categories of assets as well. Assets characterized as critical and essential facilities, including hospitals, emergency medical services, emergency shelters, water and wastewater assets, transportation, and power assets were prioritized to ensure that the building footprint, general building stock data, and site-specific asset information were coordinated. Therefore, the fidelity and integrity of site-specific asset information for non-prioritized assets

[16] Assessed property value included in the general building stock likely varies from that pulled for site-specific asset data, due to different approaches followed to assign property value to a structure or asset. The exposure and consequence analyses utilize the general building stock property values; site-specific property values are for reference only and have not been confirmed by IAG members.

must be considered when performing future analyses. This likely also results in duplicate records for assets that did not meet any of the aforementioned criteria to reconcile IAG-submitted information and assessing information.

- Due to privacy and security concerns, many privately owned utilities and service agencies conducted exposure and consequence analyses internally, and shared qualitative results with the CRB team. These results are discussed within the CRB Vulnerability Assessment, but are not incorporated within the asset inventory. See the **Infrastructure Exposure Analysis** section for more on this.
- Assessing data pulled by the CRB team that was not confirmed by an IAG member as a relevant asset is not included in the final asset inventory exposure analysis for this assessment. Nevertheless, the data is included in the inventory, listed as "unconfirmed", and any assets identified as structures have been included in the structure exposure and consequence analyses.
- It is recommended that future analyses continue to refine the asset inventory by continuing to evaluate unconfirmed IAG-related assessing data, and to continue to reconcile building footprint, general building stock, and site-specific asset data. Ultimately, the data may be used in a more efficient manner by eventually merging the datasets together. Nevertheless, security concerns will need to be evaluated and the full-reconciled dataset may not be allowable for sharing due to non-disclosure agreements and other security or privacy considerations. CRB analysts did not merge the data for this reason, as well as the need for further QAQC and continued coordination with IAG members.

2.3 Asset Inventory Attributes

Table 6 through Table 8 below provide a crosswalk of the attributes contributed by the CRB Building Footprint Data, CRB General Building Stock, and the Site-Specific Asset Inventory datasets, respectively.

TABLE 6. CRB BUILDING FOOTPRINT DATA ATTRIBUTES AND DESCRIPTION

Attribute	Field Name	Description
CRB_BLDGID	CRB_BLDGID	Building ID developed by CRB analysts to facilitate data management and QAQC.
Original ID	BUILDING_I	Original footprint ID from the source dataset.
Source	IEL_TYPE	Source of the footprint polygon.
Latitude	Latitude	Reference point of the building centroid.

Attribute	Field Name	Description
Longitude	Longitude	Reference point of the building centroid.
PTYPE	PTYPE	Building use.
Footprint Area	Shape_Area	The square footage of the building footprint.
Number of Stories	NumFloors	Expected number of stories within the building, based on height.

TABLE 7. CRB GENERAL BUILDING STOCK ATTRIBUTES AND DESCRIPTION

Attribute	Field Name	Description
CRB ID	CRB_BLDGID	Building ID developed by CRB analysts to facilitate data management and QAQC.
Latitude	Latitude	Reference point of the building centroid.
Longitude	Longitude	Reference point of the building centroid.
Number of Stories	NumFloors	Expected number of stories within the building, based on height.
PTYPE	PTYPE	Building use.
Building Elevation	LiDAR09_ft2	Sourced from 2009 LiDAR.
Total Structure Square Footage	Total_Structure_SF	Total area of the structure. Result of footprint area multiplied by the number of stories.
Footprint Area	Bldg_footprint	The square footage of the building footprint.
Square Footage Analysis	SF_Analysis	The square footage of the structure to be analyzed for flood impacts based on the requirements of the specific depth-damage function for the structure use and other characteristics. See the **Structure Damage and Contents Loss Exposure Analysis** section for more on the origins of the square footage analysis.
Mixed Use Commercial SF Analysis	MixedUseCOM_SF_Analysis	Portion of the Square Footage Analysis within mixed-use structures that is assumed to be non-residential space.
Total Commercial SF Analysis	TotalComSFAnalysis	Portion of the Square Footage Analysis in a non-residential or mixed-use building that is assumed commercial space.
Mixed Use Residential SF Analysis	MixedUseRES_SF_Analysis	Portion of the Square Footage Analysis within mixed-use structures that is assumed residential space.
Residential SF Analysis	ResidentialSFAnalysis	Portion of the Square Footage Analysis in a residential or mixed-use building that is assumed commercial space.
Total Residential SF	TotalResSFAnalysis	The total square footage of residential space in the building, regardless of flood impact exposure (different from the Square Footage Analysis).
Occupancy Map	Occupancy_Map2	Results from an analysis of the PTYPE and number of stories used to determine appropriate depth-damage functions. See the

Attribute	Field Name	Description
		Structure Damage and Contents Loss Exposure Analysis section for more information.
Hazus Code	HazusCode	Hazus occupancy class code assigned to the structure PTYPE. See the **Structure Damage and Contents Loss Exposure Analysis** section for more information.
DDF Category	DDF_Cat	Depth-damage function category. See the **Structure Damage and Contents Loss Exposure Analysis** section for more information.
Category	Category	CRB building category based on occupancy use.
Quick Category	QuickCategory	CRB building category that aggregates Categories into more broad groups to facilitate reporting of results.
Commercial	Commercial	Notes 1 if the structure is non-residential.
Residential	Residential	Notes 1 if the structure is residential.
Mixed Use	MixedUse	Notes 1 if the structure is mixed use.
DDF ID	DDF_ID	Identification number of the DDF used for the structure; informs the square footage analysis.
GEOID	GEOID10	Census tract that the structure is located in.
Percent Population	Percent_Population	Share of the population within the census tract that may reside in the building; based on amount of residential square footage in the structure and total amount of residential square footage throughout the census tract.
Population	Population	Census tract total population multiplied by the Percent Population to estimate persons that may be living with the building.
Households	Households	Number of households expected to reside in the structure, based on average household size from 2014 ACS 5-year estimates.
Facility Name	FacilityName	Placeholder for name of the asset when the general building stock is merged with site-specific asset information, if applicable.
10 Year, 50 Year, 100 Year, 500 Year AOB Losses	AOBLosses_10Year/ AOBLosses_50Year/ AOBLosses_100Year/ AOBLosses_500Year	Placeholder field for loss of function consequences to be calculated in future evaluations, if applicable.
BRV Analysis	BRV_Analysis	Building replacement value is calculated by multiplying the square footage analysis (not the square footage of the entire structure) by the building replacement value per square foot, and is based on occupancy type. If the structure is mixed use, the first two floors are assigned a non-residential building replacement value.
Alternative BRV Analysis	AltBRV_Analysis	If the structure is mixed use, the remaining floors within the square footage analysis (not the square footage of the entire structure) are assigned a residential building replacement value.
BRV	BRV	Summed BRV Analysis and Alternative BRV Analysis.

Attribute	Field Name	Description
CRV	CRV	Contents replacement value is calculated by applying the CSRV to the BRV analysis. If the structure is mixed use, the first two floors are assigned a non-residential CSRV.
Alt CRV Analysis	AltCRV_Analysis	If the structure is mixed use, the remaining floors within the square footage analysis are assigned a residential CSRV.
Total CRV	TotalCRV	Summed CRV Analysis and Alternative CRV Analysis
1-Time Disruption Cost	One_TimeDisruptionCost	Expected cost to relocate based on the square footage analysis (not the square footage of the entire structure) and occupancy type. If the structure is mixed use, the first two floors are assigned a non-residential disruption cost.
Alternative 1-Time Disruption Cost	Alt_1_TimeDisruptionCost	If the structure is mixed use, the remaining floors within the square footage analysis are assigned a residential disruption cost.
HZ Percent Owner Occupied	HZ_PercentOwnerOccupied	Percent owner-occupancy for non-residential structures, sourced from Hazus.
Residential Percent Owner Occupied	RES_PercentOwnerOccupied	Percent owner-occupancy for residential structures, sourced from American Community Survey 2014 Data.
Rent per Day	Rent_per_Day	Approximate rental rates per day for the structure based on occupancy type. If the structure is mixed use, the first two floors are assigned a non-residential rental rate. See the **Displacement Consequence Analysis** section for more information for origin of rent per day values.
Alternative Rent/Day	AltRent_per_Day	If the structure is mixed use, the remaining floors within the square footage analysis is assigned a residential rental rate.
Total Assessed Value	AssessedValue_Total	The total assessed value of the building (land plus improvements).

TABLE 8. SITE-SPECIFIC ASSET INVENTORY TEMPLATE ATTRIBUTES AND DESCRIPTION

Attribute	Field Name	Instructions to Complete (for IAG Members) and Further Description
Asset ID	AssetID	Enter here an identifier which will allow for information to be correlated between data sets that are being provided, such as GIS data.
Facility Type*	Facility_Type	Choose from the drop-down list a facility type that best represents your asset. This is meant to be general in nature and will be used as the primary classification for the asset type.
Facility Description*	Facility_Description	Further describe your asset in more detail than the Facility Type.

Attribute	Field Name	Instructions to Complete (for IAG Members) and Further Description
Facility Location*	Facility_Street_Address	List the address of the facility, including the zip code.
Longitude/Latitude*	Longitude/Latitude	Longitude and latitude of asset; not required if GIS data are provided.
Acreage of Managed Outdoor Space	Outdoor_Space_Area/ Outdoor_Space_Units	Provide acreage of managed outdoor space for recreational or social uses, if applicable.
Service Area, Population (#), or Population Description*	Service_Area_Description	Define the extent of the area for which the asset provides a service, the service population #, or describe the service population. Please indicate units provided (e.g., square miles) or specific jurisdictions / census blocks, or a specific target population (i.e., elderly, homeless, etc.) if available. Please feel free to attach a map to this response, if available.
Capacity (#) - Please include units*	Capacity_Service_Population	List the population capacity (i.e., beds) and/or the maximum extent to which the asset may operate in numbers. Please provide units.
Annual Operating Budget*	Annual_Operating_Budget	Provide your agency's budget to maintain operations of this particular asset. An estimate is acceptable.
Critical Flood Elevation, or Depth Above Grade	Critical_Flood_Depth/ Critical_Flood_Depth_Units	Most assets are considered vulnerable at the elevation at which water will touch the facility (this may be grade or first floor elevation). For public assets, the elevation of most concern is that which may result in a suspension or loss of service to that asset. Provide the critical flood elevation, if available, or the flood depth above grade at which the asset is expected to lose service as a result of floodwater.
Vertical Reference Datum	Vertical_Reference_Datum	Provide the vertical reference (datum) for the critical flood elevation; enter "n/a" (not applicable) if flood depth above grade is provided.
Criticality to Operations*	Criticality	Rank the asset's criticality to your agency's operations between 1 and 5; 5 being the most critical, 1 being asset is less necessary because of system redundancies or failure impact is not severe
Known Interdependencies - Upstream	Cascading_Impacts_Upstream	What critical assets, services, or infrastructure is this facility reliant upon? (i.e., specific power station - if unknown, identify provider)
Known Interdependencies - Downstream	Cascading_Impacts_Downstream	In the case of loss of this asset, what other impacts can be expected? For example, does the power

Attribute	Field Name	Instructions to Complete (for IAG Members) and Further Description
		supply service a pumping station that services a hospital?
Emergency Plans in Place	Emergency_Plans_in_Place	List known active emergency plans for the asset that could potentially limit loss as a result of a flood event (i.e., Emergency Action Plan (EAP), Emergency Operations Plan (EOP), service MOUs)
Age of Asset* or Date of Last Significant Renovation*	Date_Built/ Date_of_Last_Renovation/ Age_of_Asset	List the age of the asset, and the year that it last received major renovations, if available.
Estimated Replacement Value*	Replacement_Value	Provide the estimated cost that would be required to replace the asset new with comparable design and function.
Number of Personnel*	Number_of_Personnel	If the facility operates as an employer, provide the current number of employees. If the facility is a cultural asset or attracts tourism, provide the number of tourists that visit each year.
Animals Housed	Animals_Housed	Indicate whether live animals are housed at the facility (yes or no)
Distance to Alternate Facility	Alternate_Facility/ Distance_to_Alternate_Facility/ Distance_to_Alternate_Facility_Units	Provide the name of, and the distance to, the closest similar asset that could be used by the service population. This alternate facility does not have to be owned by your agency. Only applicable to essential facilities, such as hospital, police, fire, EMS.
Historical Loss*	Historical_Loss	Indicate "Yes", "No", or "Unknown" if the facility or asset has been impacted by a natural hazard in the past. This can be interpreted as physical impacts or service interruption, and may be due to any natural hazard, such as flood, high temperature, snow storm, etc.
Historical Loss Event Date	-	List the date, or name of the hazard event, of which the facility was affected. If one facility has incurred impacts on multiple occasions, please create a new record for each event.
Type of Loss Event	-	Please indicate the event that led to the loss. For example, coastal flooding, riverine flooding, inadequate drainage, wind event, high temperature, etc.).
Flood Depth Above Grade	-	Provide the depth of the water above grade for the event date.
Loss Description	-	Describe how the asset was impacted and the results of the impact. For example, how did water

Attribute	Field Name	Instructions to Complete (for IAG Members) and Further Description
		enter the facility? For how long did water remain in the facility? What were cascading impacts?
Damage Cost	-	List the amount expended to either repair or replace the asset.
Service Interruption Time	-	Provide how long (in days) that the asset was out of operation due to flooding.
Resiliency Measures Planned or Taken	-	Describe any existing or planned mitigation measures for the asset.
Comments	-	Provide any additional information you believe may be helpful. Please indicate whether recreational space is active or passive, if applicable.

3 PROPERTY

Four analyses related to risk of property to flood impacts comprise the CRB Vulnerability Assessment:

1. An exposure analysis, which considers the number and occupancy type of buildings exposed to impacts from coastal flooding and sea level rise and stormwater flooding
2. An evaluation of Boston's property value exposed flood impacts from coastal flooding and sea level rise
3. A consequence analysis of structure damage and contents loss that can be expected from coastal flooding and sea level rise
4. A consequence analysis of expected displacement costs due to flood impacts. Displacement costs are those expected to be borne by its occupants when a building becomes uninhabitable due to flood damage. The displacement consequence analysis considers one-time costs for moving and/or renting another residence, and monthly allowances for rent or storage space

Each of the aforementioned analyses were completed for the 10 percent, 2 percent, 1 percent, and 0.1 percent annual chance events, or frequencies, for three different sea level rise scenarios: 9 inches, 21 inches, and 36 inches. In total, results of the four aforementioned analyses are reported for at least 12 coastal flooding and sea level rise circumstances. Analyses that evaluate building and property value exposure to coastal and riverine flood impacts also include a fifth frequency: the average monthly highest tide for each sea level rise scenario (see the **Hazard Data Development Appendix** for the development of this scenario). The exposure analysis for stormwater flooding considers the 10 year, 24 hour rain event for the same sea level rise scenarios. This methodology explains the process and approach performed by CRB Analysts to yield the results of each analysis.

3.2 Structure Exposure Analysis

The structure exposure analysis examines the structures at risk to coastal flooding and sea level rise circumstances, as well as stormwater flooding scenarios. Once CRB analysts finalized the general building stock, the exposure analysis was conducted in ArcGIS using the "Select by Location" tool. CRB analysts used the intersection feature of the tool, and selected structures that were either fully or partially within the flood inundation area. Results were exported into GIS, where analysts compiled the data and examined the results for trends in the number and occupancy type of buildings by neighborhood. The Citywide Vulnerability Assessment and the Focus Area assessments describe trends; exposure data for all of Boston is located in the **Detailed Result Appendix**.

3.2.1 Exposure Analysis Limitations

- Results of the exposure analysis are dependent upon the accuracy and integrity of the general building stock, and thus the exposure analysis must continue to be updated and maintained with the general building stock
- The exposure analysis for stormwater flooding scenarios selected buildings that intersected the stormwater flood extents with a -1 foot buffer. The negative buffer was used to eliminate buildings that had miniscule ponding areas located within a building footprint, as analysts considered such instances to be errors in the hazard data.
- Exposure by definition does not consider site-specific conditions such as structure elevations and flood elevations, but simply identifies structures that may be exposed to a number of flood impacts such as structural damage, contents loss, property value degradation, and access issues.
- This analysis imposes future expected conditions on the current building stock. The analysis assumes no change to the existing building stock.

3.3 Property Value Exposure Analysis

The approach to conduct the Property Value Exposure Analysis mirrors that described in the **Structure Exposure Analysis** section above, and adds the assessed value of exposed property (building value and land value) to the evaluation. The Boston Assessing data provides the assessed value for most assessing records; assessed value is the valuation placed on a property for the purposes of taxation (See Footnote 11). Trends related to property value exposure is provided in the CRB Citywide Vulnerability Assessment and Focus Area assessments; raw data on exposed property value by structure use category for all of Boston and each focus area is provided in the **Detailed Result Appendix.**

3.3.1 Property Value Exposure Analysis Limitations

- The Property Value Exposure Analysis only considers property value exposed to coastal flood impacts. Value of property exposed to stormwater impacts are not evaluated.[17]

[17] Properties with known (mapped) flood risk are also known to experience loss in market value over time, due to the potential for increased operating costs, as well as perception of decreased long term viability. Please see the Citywide Vulnerability Assessment for more on this concept. As stormwater flood risk is unlikely to be mapped for flood insurance

- Only property with existing structures exposed to coastal flood and sea level rise impacts are considered in this analysis, because the property value is linked with the **Structure Exposure Analysis**. Empty lots have not been considered.
- City assessing data provides one comprehensive assessing record for a condominium. This record is the Condo Main. CRB analysts assume that Condo Main records report the property value for all records within a condominium, and used the Condo Main record to obtain property value for condominiums. Any parcels with a Condo Main PTYPE (995) were assigned the Condo Main assessed value in GIS; this value was then distributed across buildings on the parcel as described above.
- This analysis imposes future expected conditions on the current building stock. The analysis assumes no change to the existing building stock.

3.4 Infrastructure Exposure Analysis

The Infrastructure Exposure Analysis is similar to the Structure Exposure Analysis in that it examines the location of infrastructure assets and systems in relation to expected extents of coastal and riverine flooding with sea level rise, as well as stormwater flooding scenarios. The Infrastructure Exposure Analysis differs, in that not all infrastructure assets are located within a structure and that much of the data is maintained in point and polyline files. This is particularly the case with the transportation infrastructure system, such as roads, tunnels, bridges, and other underground assets. As such, CRB analysts conducted the Infrastructure Exposure analysis in ArcGIS using the "Select by Location" tool and incorporated a 15-foot buffer to account for assets that are structure-based, so that any exposure of the asset to flood impacts was considered in the analysis. CRB analysts manually screened each infrastructure asset to confirm exposure to the various flood frequencies and sea level rise scenarios analyzed within this report. Due to data sensitivity and integrity concerns, the exposure analysis was limited to the below categories. IAG members had the choice of conducting their own exposure and consequence analysis using the CRB's coastal and riverine flood hazard data. These members provided a qualitative description of expected effects of various coastal and riverine flood hazard conditions to CRB analysts for inclusion in the report.

Results of the exposure analysis are presented within each focus area of the Vulnerability Assessment. Evaluation may be presented qualitatively within the Vulnerability Assessment, or in a custom format,

purposes (and may be addressed through direct infrastructure improvements), the property market value exposure analysis does not add the same informative value for understanding stormwater flood risk.

for some sectors and assets owned by specific entities required non-disclosure agreements in order to share data or analyses.

- Public transit assets (including commuter rail, bus routes, and rapid transit)
- Evacuation routes
- Central artery routes
- Hospitals and health centers
- Schools, colleges, and universities
- Publicly-available utility asset information
- Emergency service information (police, fire, emergency medical services, emergency shelters)
- Public housing

3.4.1 Exposure Analysis Limitations

- Results of the exposure analysis are dependent upon the accuracy and integrity of the asset inventory, and thus the exposure analysis must continue to be updated and maintained with the asset inventory.
- Exposure by definition does not consider site-specific conditions such as critical flood elevations for particular infrastructure assets, but simply identifies infrastructure assets that may be exposed to a number of flood impacts such as structural damage, contents loss, property value degradation, and access issues. Furthermore, exposure does not consider full or partial loss of function of infrastructure assets for this reason.
- The exposure analysis does not include all infrastructure assets due to data limitations, as well as privacy and security concerns raised by members of the IAG.

3.5 Structure Damage and Contents Loss Consequence Analysis

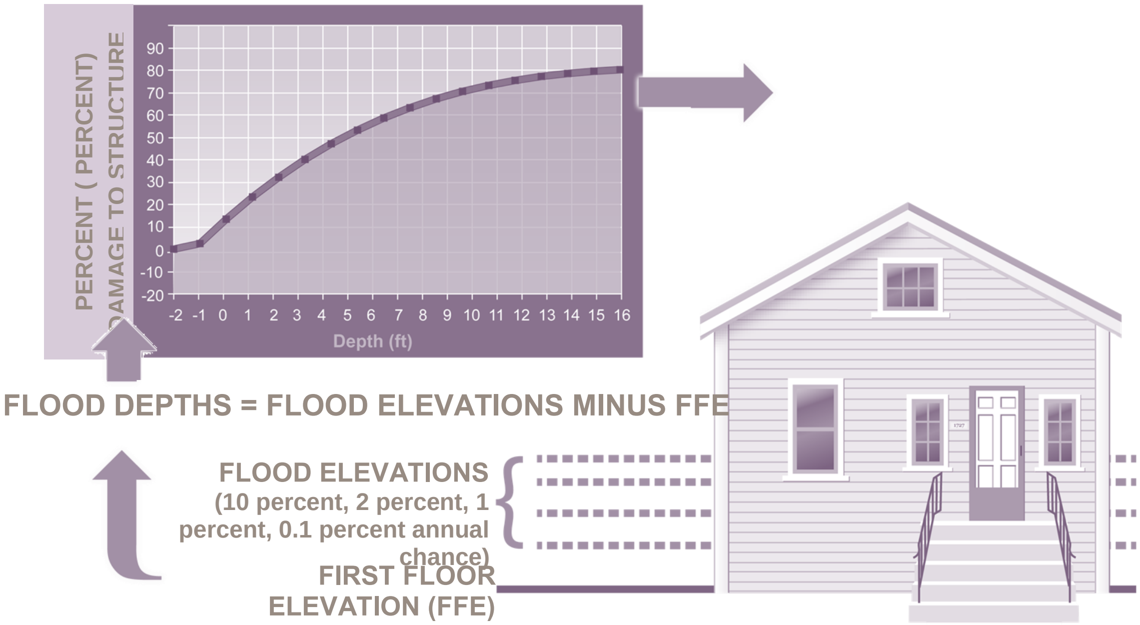
The Structure Damage and Contents Loss Consequence Analysis examines risk to coastal and riverine flooding and sea level rise to buildings and their contents. The consequence analysis does not consider stormwater impacts because the stormwater hazard data is not intended for use to assess individual parcels for flood impacts.

Property losses are evaluated based on depth damage functions (DDFs) developed by the United States Army Corps (USACE) following Hurricane Sandy; flood depths at each structure are cross referenced with DDFs to provide expected percent loss for each structure and its contents. This percent loss is then translated to property loss based on structure replacement costs. The following section provides a detailed discussion of how expected property losses were calculated for the 12 modeled coastal storm and riverine flood circumstances. The CRB Vulnerability Assessment categorizes property loss as structural damage (damage to the building) and contents losses (damage to personal property or inventory). All property damage results have been calculated for Boston using the CRB general building stock as of October, 2016, using 2016 replacement cost values as calculated using RS Means.

3.5.1 Depth Damage Functions

Analysts calculated potential property damages associated with the modeled flood scenarios using standardized DDFs specific to the characteristics and occupancy of a structure. A DDF correlates the depth, duration,[18] and type of flooding to a percentage of expected damage to a structure and its contents, including inventory. The USACE produces DDFs that can be used to model direct physical damages. Following Hurricane Sandy, the USACE developed DDFs specific to the Northeast for coastal flooding in a report titled the North Atlantic Coast Comprehensive Study (NACCS). As this information contains the most current and best available data, analysts used these functions to evaluate direct physical damages. The image below provides an illustration of how DDFs are applied. Figure 2 provides a sample depth damage relationship from the USACE NACCS.

[18] Duration is not a modeled output in the hazard data used for the evaluation. Duration is assumed within the DDFs based on the flood source type.



Example application of depth damage functions adapted from FEMA's Benefit Cost Analysis Training Unit 3[19]

Coastal flooding DDFs are specific to hazard conditions and the primary cause of damage: inundation, wave, or erosion. Saltwater inundation DDFs obtained from the NACCS study were used by analysts to model damages as a result of coastal and riverine flooding with sea level rise.

3.5.2 Data Sources

BCA analysts utilized the following data sources to calculate expected structure, contents and inventory losses avoided:

- **CRB General Building Stock (2016).** Nearly all attributes in the CRB General Building Stock were used to determine physical damages, including square footage, number of stories, building elevation, and building use.
- **RS Means Building Construction Cost Data (2016):** This publication provides location-specific building replacement square foot costs for 160 building occupancy types. Using RS Means,

[19] It should be noted that calculations typically involve the 10 percent, 2 percent, 1 percent and 0.2 percent annual chance events. The CRB has substituted the 0.2 percent annual chance event with the 0.1 percent annual chance event in order to understand impacts at that severity of storm. As such, damage cost calculations may be conservative compared to if the 0.2 percent annual chance had been incorporated.

analysts calculated building replacement square foot costs for the various structure types in Boston.

- **USACE North Atlantic Coast Comprehensive Study (NACCS) Physical Depth Damage Function Summary Report (2015):** Following Hurricane Sandy, the USACE collected empirical data to estimate the damages that would occur from future events. This report produced coastal damage functions for residential, non-residential, and public property. DDFs were obtained from this study to estimate direct physical damages related to modeled storm surge scenarios.
- **USACE West Shore Lake Pontchartrain Hurricane and Storm Damage Risk Reduction Study (2014):** This study conducted by the USACE produced contents-to-structure ratio values (CSRVs) for residential and non-residential structures. CSRVs were used as a percentage of the total building replacement values to determine total contents replacement values for structures in the project area. While produced for a separate region, analysts determined this study to be the best and most recent data available for use with the DDFs.
- **Modeled Inundation Depth Data with Sea Level Rise:** Flood elevations for the 10 percent, 2 percent, 1 percent, and 0.1 percent storm events determined approximate flood depths inside structures. Each of the four frequencies were considered for three different sea level rise scenarios: 9 inches, 21 inches, and 36 inches. In total, 12 situations of damage estimates were evaluated.

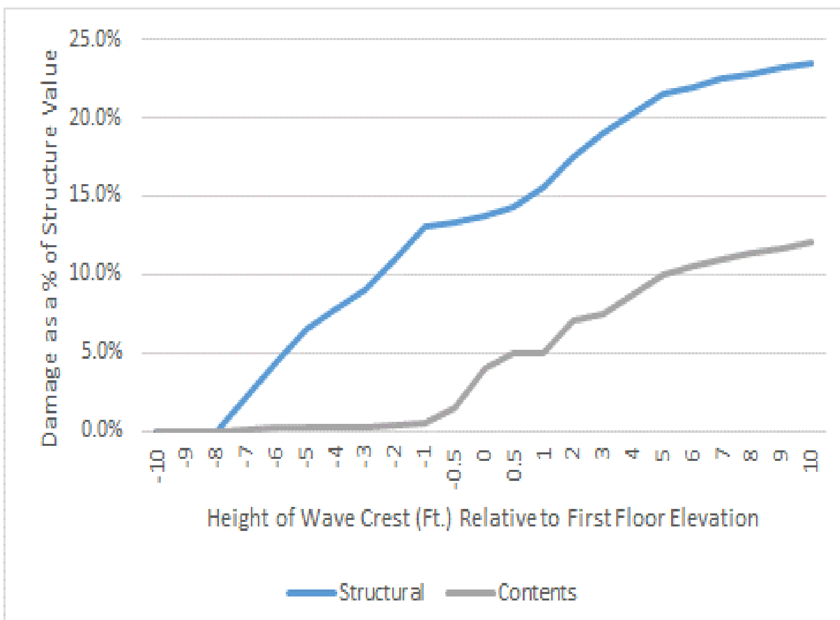


FIGURE 2. EXAMPLE EXPECTED STRUCTURAL AND CONTENTS DAMAGE FROM INUNDATION, NACCS URBAN HIGH RISE PROTOTYPE. DAMAGE AT NEGATIVE FLOOD DEPTHS ACCOUNTS FOR IMPACTS TO MECHANICAL, ELECTRICAL, AND PLUMBING SYSTEMS THAT MAY BE LOCATED AT OR BELOW GRADE.

3.5.3 Analysis Steps

Map Structure Type and Occupancy to Depth

Damage Functions, Replacement Values, and Hazus Occupancy Types

Structures may be classified according to both construction features (type) and use (occupancy). Building types and occupancies can be mapped to classifications used by RS Means to estimate replacement value for the structure. Each mapping to PTYPE required an independent evaluation. Analysts completed the following mappings based on PTYPEs:

- PTYPEs to USACE NACCS prototypes to assign appropriate DDFs
- PTYPEs were mapped to Hazus occupancy classes[20] to estimate a replacement value for structures, as well as apply the appropriate displacement and restoration time multipliers, one-time disruption costs, and for certain uses, the percent owner occupancy

Complete Square Footage Analysis

Damages to NACCS prototypes must be assessed based on the square footage within a certain number of stories NACCS identifies for each prototype's damage function.[21] The number of stories analyzed by the DDF is related to the structure type and the expected location and value of mechanical, electrical, and plumbing (MEP) assets in buildings. A significant portion of a building's value is captured in MEP assets; damage costs to these assets can therfore be disproportionate to those of other contents. Urban high rise damage functions, for example, analyze damages as a percent of the square footage of the first ten floors given the NACCS assumption that MEP assets are located within the basement or first floor of the structure.

To calculate the structure square footage for the consequence analysis, analysts multiplied the square footage per floor by the prototype number of stories identified in the USACE NACCS (refer to Table 9 for an example) or the total number of stories, whichever is less, for each structure. Certain PTYPEs represent structures that are of mixed uses. For structures identified as mixed use, an analysis square footage is developed for both residential and commercial square footage. CRB analysts used the analysis square footage to calculate the building and contents replacement value relavent for the analysis.

TABLE 9. USACE NACCS, NUMBER OF STORIES PER PROTOTYPE/DEPTH DAMAGE FUNCTION ANALYSIS (EXAMPLE)

Prototype No.	Building Types	Stories (for Analysis)

20 Hazus occupancy classes are a building occupancy classification system developed by FEMA Hazus-MH Flood Technical Manual to categorize like buildings so that standard values can be applied to similar structure types.

21 U.S. Army Corps of Engineers. North Atlantic Coast Comprehensive Study (NAACS). http://www.nad.usace.army.mil/CompStudy

1A-1	Apartment 1-Story, No Basement	1
1A-3	Apartment 3-Story, No Basement	3
2	Commercial Engineered	2
3	Commercial Non-Engineered	1
4A	Urban High Rise	10
4B	Beach High Rise	10
5A	Residential 1-Story, No Basement	1
5B	Residential 2-Story, No Basement	2
6A	Residential 1-Story, With Basement	1
6B	Residential 2-Story, With Basement	2
7A	Building on Open Pile Foundation	1
7B	Building on Pile Foundation with Enclosures	1

Source: North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk. Physical Depth Damage Function Summary Report. January 2015.

Calculate the Building and Contents Replacement Value

Building replacement values (BRVs) and Contents Replacement Values (CRVs) are required to determine expected damage to buildings. These values are ultimately applied to the analysis square footage and the percent structural and contents damage related to the flood depth in the DDFs to determine expected damages. Analysts used RS Means 2016 Square Foot Costs to obtain replacement values.

Replacement values are different from the assessed market value referenced above, because it is considered an estimate of the cost to construct an identical structure of the same type and occupancy using today's market values for materials, labor costs, and considering new technologies and regulations that may affect the construction process.

Building Replacement Value (BRV)

The BCA Re-engineering Guide defines the BRV as "the building replacement value for a specific component of the building, expressed in dollars".[22] CRB analysts used the Hazus occupancy classes[23] and obtained building replacement values from RSMeans square footage costs for each occupancy class.

22 Federal Emergency Management Agency. Benefit Cost Analysis Re-engineering Guide. Full Flood Data. 2009. Located at: http://www.fema.gov/media-library-data/20130726-1738-25045-2254/floodfulldata.pdf

23 Hazus occupancy classes represent a certain building type based on use, and the FEMA Hazus-MH Flood Technical Manual applies an average square footage to each occupancy class. This average square footage was used to choose the appropriate replacement value per square foot from the RSMeans cost data book.

RSMeans is a construction cost-estimating resource published each year often used by engineers to evaluate different construction cost possibilities. Labor and material costs are captured and other information such as city cost indexes, productivity rates, crew composition, and contractors overhead and profit rates are available. Analysts used the appropriate RSMeans city cost indices of 1.23 for residential uses and 1.18 for commercial uses in order to accommodate Boston-specific construction conditions. Table 10 below shows the BRV values determined from RSMeans that are applicable to this analysis with the city cost index increase for Boston. The building replacement value represents the cost to repair or rebuild damaged buildings in current dollars.

Mixed Use Building Occupancies

It is common for multiple story buildings to serve multiple uses in Boston. Analysts identified mixed-use structures using PTYPES, and assumed that commercial areas are contained to the first two floors of a structure, if the building is over two stories tall. If the building is two stories tall, analysts assumed that the first floor is commercial space. This assumption was confirmed through the quality control review described in the **Building Information Assumptions and Limitations Section.** RSMeans multiplied the commercial BRVs and the residential BRVs by the area of the commercial and residential space within a building, respectively, and added the values together to obtain a total BRV for the analyzed square footage of the building.

Contents Replacement Value (CRV)

The USACE NACCS does not include content replacement ratios, therefore CRB analysts used the next best available data. The CRV is based on the contents-to-structure ratio values (CSRV) for residential and non-residential structures from data obtained through surveys in the *West Shore Lake Pontchartrain Hurricane and Storm Damage Risk Reduction Study.*[24] The total building and contents exposure for the analysis square footage provide a general understanding of the total value of building square footage (and its contents) at risk to flooding in the project area from the 1 percent annual chance flood event. The CSRVs used in the analysis are shown in Table 10. To calculate the total contents replacement value, analysts multiplied the total BRV by the appropriate CSRV, which is mapped to the Hazus occupancy class. Because the contents values are based on percentages, they increase coincident with an increase in the BRV and therefore do not need to be updated to Boston values for this analysis.

Mixed Use Building Occupancies

24 USACE. 2014. West Shore Lake Pontchartrain Hurricane and Storm Damage Risk Reduction Study – Final Integrated Feasibility Study Report and Environmental Impact Statement. November.

- The CSRV for a specific type of residential or commercial use was assigned to the appropriately categorized analysis square footage
- Next, the CSVR was applied to the BRV to obtain the CRV for each use type
- The CRV for all use types analyzed in the analysis square footage were added together to obtain the total CRV

TABLE 10. REPLACEMENT VALUES

Hazus	Occupancy Code	BRV	CSRV	CRV
RES1	Single Family Dwelling	$143.14	0.69	$98.77
RES2	Mobile Home	$137.47	1.14	$156.71
RES3A	Multi Family Dwelling - Duplex	$117.76	0.69	$81.25
RES3B	Multi Family Dwelling – 3-4 Units	$227.31	0.69	$156.85
RES3C	Multi Family Dwelling – 5-9 Units	$227.31	0.69	$156.85
RES3D	Multi Family Dwelling – 10-19 Units	$216.42	0.69	$149.33
RES3E	Multi Family Dwelling – 20-49 Units	$209.84	0.69	$144.79
RES3F	Multi Family Dwelling – 50+ Units	$202.67	0.69	$139.84
RES4	Temporary Lodging	$211.01	0.69	$145.59
RES5	Institutional Dormitory	$242.70	0.69	$167.46
RES6	Nursing Home	$246.88	0.69	$170.35
COM1	Retail Trade	$137.67	1.19	$163.82
COM2	Wholesale Trade	$133.41	2.07	$276.16
COM3	Personal and Repair Services	$160.45	2.36	$378.66
COM4	Business/Professional/Technical Services	$198.63	0.54	$107.26
COM5	Depository Institutions	$299.43	0.54	$161.69
COM6	Hospital	$426.82	0.54	$230.48
COM7	Medical Office/Clinic	$241.96	0.54	$130.66
COM8	Entertainment & Recreation	$252.25	1.7	$428.83
COM9	Theaters	$211.95	0.54	$114.45
COM10	Parking	$89.34	0.54	$48.24
IND1	Heavy	$151.75	2.07	$314.12
IND2	Light	$133.41	2.07	$276.16
IND3	Food/Drugs/Chemicals	$205.59	2.07	$425.56
IND4	Metals/Minerals Processing	$205.59	2.07	$425.56
IND5	High Technology	$205.59	2.07	$425.56
IND6	Construction	$133.41	2.07	$276.16

Hazus	Occupancy Code	BRV	CSRV	CRV
AGR1	Agriculture	$133.41		$0.00
REL1	Church/Membership Organizations	$213.29	0.55	$117.31
GOV1	General Services	$169.99	0.55	$93.49
GOV2	Emergency Response	$283.68	1.5	$425.52
EDU1	Schools/Libraries	$228.41	1	$228.41
EDU2	Colleges/Universities	$200.58	1	$200.58

Determine Flood Depths Based on Modeled Flood Scenarios

Analysts subtracted grade elevations for each structure footprint in the study area from the modeled 10 percent, 2 percent, 1 percent, and 0.1 percent flood elevations for each sea level rise scenario in order to determine the expected flood depths in structures. The DDFs provided in the USACE NACCS account for expected first floor elevation (FFE) by occupancy type and age, as well as the presence of MEP assets located in the basement. Since these building attributes have been incorporated into the DDFs, it is not necessary to account for FFE in the structure inventory. Nevertheless, many of the structures in the study area have FFEs at grade or are split level homes that have living space or basements vulnerable to flooding at or below grade elevation (confirmed through Google Earth). To determine the depth of flooding for structures in the study area, analysts obtained the maximum modeled flood elevation within a building footprint for each flood scenario. The average grade elevation within the building footprint was then subtracted from the respective flood elevations to obtain a flood depth in each structure for each scenario.

Calculate Percent Damage and Physical Loss Values

As previously mentioned, DDFs are a relationship between the depth of floodwater in a structure and the percent of damage that can be attributed to the flooding. Once the expected flood depths were defined for each storm surge scenario, analysts applied the DDFs to estimate the percent of structural and contents damage costs. The percent of structural and contents damage is related to 1-foot depth increments, and are multiplied by a structure or contents total replacement value to produce a physical loss value in dollars.

3.5.4 Quality Control Evaluations

In order to reduce uncertainties and increase the accuracy of the evaluation, analysts performed several quality control actions as described in the following subsections.

3.5.4.1 QA/QC of PTYPES

As discussed in the **Data Integrity and Fidelity** section of this report, PTYPES were confirmed through Google Streetview, especially of those buildings that had the highest damage calculations in a focus area. Adjustments were made where appropriate. Any structures for which accurate building occupancies were unclear were subject to a site-specific evaluation using GIS and Google Earth street view, as well as by consulting with team members with specific local knowledge.

3.5.4.2 QA/QC of Direct Physical Damages

Structures that experienced a high percent loss and/or those with high replacement costs required site specific analysis. Analysts reviewed PTYPES, expected flood depths, ground elevation, DDF, and replacement value to ensure the accuracy of the data and the expected damages. Many inaccuracies were due to incorrect assignment of PTYPES to a building. This data point informs the DDF that is used to determine the percent damage. Furthermore, accessory structures and utility buildings were removed from the analysis due to the absence of appropriate DDFs in the NACCS model inventory for these uses and the associated risk of under or overestimating losses.

3.5.5 Assumptions

- The USACE NACCS DDFs account for underground networks by applying a percent damage for negative flood depths. The underground networks of the City could not be analyzed due to security concerns, lack of available data, and budget / time constraints.
- The NACCS DDFs did not provide percent loss for all flood depth intervals for all occupancies, and provided no percent loss above ten feet of flood depth. As such, analysts developed trend interpolations based on the preceding three available flood depths for missing DDFs. A similar approach was used for flood depth gaps below zero flood depth, using averages between flood depths, where available.
- The DDFs do not assume complete loss beyond 50 percent damage, as is often assumed for use with benefit cost analyses, as well as substantial damage determinations. Further, the impacts of codes and standards in restoration are not considered in the analysis. As such, direct physical damage costs may be conservatively low.
- For PTYPES that contain a mixture of residential and commercial uses, commercial occupancies are assumed to be located on the bottom two floors with residential above (for structures with over two stories).

3.6 Displacement Consequence Analysis

Displacement costs are those borne by occupants during the time when a building becomes uninhabitable due to expected flood damage, and are applicable to both residential and non-residential property owners. To determine displacement values, CRB analysts consider two interrelated methodologies, which estimate the time and cost of displacement for various building types: relocation costs and business interruption costs.

Relocation costs and business interruption are two consequences that result from disaster impacts. Relocation costs are associated with moving a household or a business to a new location and resuming life or business in that new location. Business interruption is associated income lost as a result of an event that interrupts the operations of the business, or the removal of a piece of real estate, both rental and sale properties, from the market as a result of disaster impacts.

Relocation costs are derived from displacement time, while business interruption is based on restoration time (refer to Figure 3). Some businesses may relocate and resume business elsewhere; some businesses may be unable to relocate while they are displaced. Therefore, impacted businesses or residents may incur both, one, or neither of relocation costs and business interruption. For example, a business may have to restock its damaged inventory before being able to relocate and start operations in a new space, thus incurring both business interruption and relocation costs.

Displacement Time	Restoration Time
• Derived from DDFs that relate a depth of flooding to an amount of time that a structure is not usable. • Relocation costs are based on displacement time.	• Time for physical restoration of the damage of the building, as well as time for clean up, inspections, permits, and delays due to contractor availability. • Based on occupancy type, flood depth, and extent of damage. • Business interruption costs are based on restoration time.

FIGURE 3. DISPLACEMENT AND RESTORATION TIME COMPARISON

CRB Analysts took care to appropriately account for each cost associated with displacement without duplication by applying a FEMA Hazus Business Interruption Time Multiplier, categorized by business type, to restoration time. The overall approach taken to identify appropriate relocation costs and business interruption is as follows:

1. Identify flood depths and damage expected to occur in 1 percent, 2 percent, 1 percent, and 0.1 percent annual chance flood events within Boston for three sea level rise scenarios
2. Calculate expected displacement and building restoration times based on flood depths and building use
3. Apply Business Interruption Time Multipliers to restoration time based on Hazus occupancy class and extent of damage
4. Use displacement and adjusted building restoration times to calculate relocation costs and business interruption without benefit duplication

3.6.1 Data Sources

- **Hazus-MH 2.1 Flood Technical Manual and Earthquake Technical Manual:** Methodologies from Hazus-MH 2.1 were used to determine restoration time, as well as the costs of relocation, supplemented with local rental rates. Specifically, the Flood Technical Manual provided restoration time and the Earthquake Technical Manual provided the Business Interruption Time Multipliers based on damage category.[25]
- **Hazus 2.1 One-time Disruption Cost Defaults**: Hazus provides national one-time relocation costs per square foot based on Hazus occupancy class. These costs are provided in 2006 dollars and have been normalized to 2016 dollars based on inflation.
- **US Census Bureau American Community Survey (2014)**: The percent owner occupancy by census tract for residential uses was obtained from local 2014 American Community Survey five year estimates.

25 The Earthquake Technical Manual is applicable because of the hazard neutral approach to loss of function; additionally, Hazus methodologies related to flood hazard are often adapted from methods developed for the earthquake hazard. While the cause and extent of damage differ for these two hazard types, the consequences of such hazards (damage, displacement, loss of function) are generally the same. As such, the Flood Technical Manual will often refer to the Earthquake counterpart for greater detail, as was the case in obtaining information for detailed calculations necessary to determine business interruption.

- **Hazus 2.1 Percent Owner Occupancy Defaults**: Hazus provides percent owner occupancy for non-residential uses by Hazus occupancy class (local value was not available).
- **Hazus 2.1 Business Interruption Time Modifiers**: Modifiers represent median values for probability of business or service interruption for Hazus occupancy classes, based on damage state and restoration time.
- **Direct Physical Damages**: Flood impacts were modeled for different flood scenarios to determine which structures are expected to flood and the depth of flooding within the structure (see **Structure Damage and Contents Loss Consequence Analysis** above).
- **FEMA BCA Toolkit 5.1**: Depth displacement tables were not provided with the USACE NACCS DDFs used in the Direct Physical Damage evaluation. As such, analysts extracted displacement tables from the Toolkit to estimate displacement time for structures based on flood depth.
- **Local Rental Rates.** Analysts researched local rent rates for Boston neighborhoods and applied these rates by occupancy. Local residential rental rates were established from an online survey of different sizes and types of residential spaces currently available for rent within Boston. Local commercial rental rates were obtained in the same manner as residential rental rates; neighborhood-specific rental rates were developed for both residential and non-residential rentals. Loopnet was used to obtain current asking commercial rental rates, and Trulia, and Zillow (all online real estate services) were used to conduct the survey.

3.6.2 Analysis Steps

The following steps were taken in order to determine expected displacement impacts for different modeled flood circumstances.

1. Identify Impacted Structures: The **Structure Damage and Contents Loss Consequence Analysis** identified structures expected to be impacted at the 10 percent, 2 percent, 1 percent, and 0.1 percent annual chance events for three sea level rise scenarios.
2. Identify Impacted Square Footage: The total impacted square footage per occupancy class was identified by using the total square footage of the first floor for structures that are expected to experience less than ten feet of flooding. The total square footage of the first two floors is used for structures experiencing more than ten feet of flooding.

3. Identify and Apply Percent Owner Occupied by Occupancy: For residential uses, census tract data provided the percent owner occupied. All non-residential uses were assigned default percent owner occupancy obtained from Hazus-MH 2.1.

4. Identify Rental Rates by Occupancy: Analysts calculated an average annual rent price per square foot for residential and non-residential uses in Boston, identifying specific rental rates per neighborhood. These values were converted to an average price per square foot per day (Price/SF/Day), for use in the Relocation Costs calculation outlined in Step 6.

5. Evaluate Displacement Time: The estimated flood depth within each structure is correlated to USACE depth displacement tables to estimate displacement time for each modeled flood scenario.

6. Process Relocation Costs: The Hazus Flood Technical Manual provides guidance to calculate relocation costs to building occupants based on occupancy type:[26]

$$\mathbf{REL_i = \Sigma \text{ if } percentDAM - BL_{i,j} > 10 \text{ percent}: Fa_{i,j} * [\,(1 - percentOO_{\mathit{i}}) * (DC_1) + percentOO_i * (DC_i + RENT_i * DT_{i,j})]}$$

Where:

REL_i	Relocation costs for occupancy class l (in dollars)
$Fa_{i,j}$	Floor area of occupancy group i and depth j (in square feet)
PercentDAM - $BL_{i,j}$	Percent building damage for occupancy i and water depth j, (from depth-damage function), if greater than 10 percent
DC_i	Disruption costs for occupancy i (in dollars)
$DT_{i,j}$	Displacement time (in days) for occupancy i and water depth j (in days)
$percentOO_i$	Percent owner occupied for occupancy l
$RENT_i$	Rental cost for occupancy l (in $\$/ft^2/day$)

26 It is important to note that this equation incorporates only owner-occupied structures when calculating displacement values. The reason for this is that a renter who has been displaced would likely cease to pay rent to the building owner of the damaged property, and instead would pay rent to a new landlord. As such, the renter could reasonably be expected to incur no new rental expenses. Conversely, if the damaged property is owner-occupied, then the owner will have to pay for new rental costs in addition to any existing costs while the building is being repaired. This model assumes that it is unlikely that an occupant will relocate if a building is slightly damaged (less than 10 percent structure damage).

7. Evaluate Restoration Time: The estimated flood depth within each structure cross-referenced to the restoration time by occupancy provided by the Hazus 2.1 Flood Hazard Technical Manual[27] to determine the restoration time for each modeled flood scenario.

8. Assign Damage State: CRB analysts assigned FEMA damage states to each impacted structure based on the percent damage to each structure for each modeled flood scenario (see Table 11). Percent damage is evaluated based on the flood depth within a structure.

TABLE 11. DAMAGE STATE CORRELATIONS

Damage State	None	Slight	Moderate	Extensive	Complete
Correlating Percent Damage Threshold	0%	1%	5%	25%	50%+

9. Determine Business Interruption Time (Adjusted Restoration Time): Business interruption time determined by applying the Business Interruption Time Multiplier to expected restoration periods. Business Interruption Time Multipliers vary based on occupancy and damage state. CRB analysts calculate business interruption costs in accordance with the methodology described in the **Economy** section. Multipliers are provided in Table 12 below.

TABLE 12. HAZUS TIME MULTIPLIERS BY OCCUPANCY CODE

HAZUS Occupancy Code	OC Description	Damage State				
		None	Slight	Moderate	Extensive	Complete
RES1	Single Family Dwelling	0	0	0.5	1	1
RES2	Manufactured Housing	0	0	0.5	1	1
RES3	Multifamily	0	0	0.5	1	1
RES4	Hotel/Temporary lodging	0	0	0.5	1	1
RES5	Institutional Dorm	0	0	0.5	1	1
RES6	Nursing Home	0	0	0.5	1	1
COM1	Retail Trade	0.5	0.1	0.1	0.3	0.4
COM2	Wholesale Trade	0.5	0.1	0.2	0.3	0.4
COM3	Personal and Repair Services	0.5	0.1	0.2	0.3	0.4
COM4	Profession/Tech/Business Services - Office	0.5	0.1	0.1	0.2	0.3

[27] The Hazus Technical Manual provides value ranges for restoration time. Analysts used the upper and lower bounds of these ranges for thresholds correlated to flood depths and interpolated the values in between any missing intervals.

COM5	Banks	0.5	0.1	0.05	0.03	0.03
COM6	Hospital	0.5	0.1	0.5	0.5	0.5
COM7	Medical Office/Clinic	0.5	0.1	0.5	0.5	0.5
COM8	Entertainment and Recreation	0.5	0.1	1	1	1
COM9	Theaters	0.5	0.1	1	1	1
COM10	Parking	0.1	0.1	1	1	1
IND1	Heavy	0.5	0.5	1	1	1
IND2	Light	0.5	0.1	0.2	0.3	0.4
IND3	Food/Drugs/Chemical Lab	0.5	0.2	0.2	0.3	0.4
IND4	Metals/Minerals Processing	0.5	0.2	0.2	0.3	0.4
IND5	High Technology/Lab	0.5	0.2	0.2	0.3	0.4
IND6	Construction	0.5	0.1	0.2	0.3	0.4
AGR1	Agriculture	0	0	0.05	0.1	0.2
REL1	Church	1	0.2	0.05	0.03	0.03
GOV1	General Services (Town Hall)	0.5	0.1	0.02	0.03	0.03
GOV2	Emergency Response (Police Station)	0.5	0.1	0.02	0.03	0.03
EDU1	Schools/Libraries	0.5	0.1	0.02	0.05	0.05
EDU2	Colleges/Universities	0.5	0.1	0.02	0.05	0.05

10. Complete the Analysis: The analysis described above was completed for damages expected at four recurrence intervals (10 percent, 2 percent, 1 percent, and 0.1 percent annual chance flood events) for three sea level rise scenarios (9 inches, 21 inches, 36 inches) to estimate Relocation costs and Business Interruption Time.

3.6.3 Assumptions

The following assumptions were made to prevent double-counting benefits associated with relocation costs and business interruption costs:

- Both relocation costs and business interruption are only calculated for floors expected to be directly impacted by floodwaters. In reality, there are times when the entire structure will be displaced as a result of flood impacts. As a result, this approach produces conservative results.
- **Relocation-specific Assumptions:**

  - Depth displacement tables used in the analysis do not consider flooding below grade. Utilities and other critical assets often lie below grade within Boston. When these areas flood, occupants may be displaced, even if flood waters do not reach above the first floor. Such displacement is not captured in the analysis.
  - The depth displacement tables do not extend beyond 16 feet of flood depth. As such, displacement periods for flood depths above 16 feet are assumed to match the time period for displacement at 16 feet.

- **Business Interruption-specific Assumptions:**
  - FEMA assumes that business interruption does not occur until the building reaches greater than 10 percent structural damage.
  - Some businesses will choose to relocate their operations while structure damage is being repaired to minimize output loss. To do so, these businesses may rent additional space elsewhere, thus choosing to incur relocation costs during building restoration as opposed to economic losses; this scenario assumes that business output will remain the same upon relocation.
  - The analysis assumes that all interrupted businesses are eventually able to return to business as usual. This a conservative assumption; FEMA's Institute for Business and Home Safety states that "one-fourth of all businesses that close because of a disaster never reopen." This number is statistically considerably higher for small businesses (roughly 40 percent).
  - Analysts assume, in concurrence with Hazus 2.1, that businesses that qualify as entertainment (COM8), theatres (COM9), parking facilities (COM10), and heavy industry (IND1) will not relocate after a disaster due to the type of activities that take place in such structures. As such, no relocation costs are associated with these uses, though business interruption costs are calculated.
  - The Hazus Technical Manual provides value ranges for restoration time. Analysts used the upper and lower bounds of these ranges for thresholds correlated to flood depths and interpolated the values in between any missing intervals.

4 PEOPLE

The CRB Vulnerability Assessment analyzed how climate-related hazards, coastal and riverine flooding with sea level rise in particular, may affect Boston residents. These analyses include the following:

1. An exposure analysis, which considers the number of people that live in residential structures exposed to impacts from coastal, riverine, and stormwater flooding with sea level rise.
2. A consequence analysis, which reflects the number of impacted residents that may need to shelter if they cannot access their homes due to coastal and riverine flooding, specifically. Shelter needs are based on flood depths and population characteristics such as age and income.
3. A consequence analysis of expected psychological distress as a result of property damage or displacement, also known as Mental Stress and Anxiety impacts, as a result of coastal and riverine flooding. The cost of treatment for post-disaster mental health impacts is the basis of this consequence analysis.
4. A consequence analysis of expected work productivity impacts as a result of mental illness, which reflects an estimate of lost work days for people whose residences are impacted by coastal and riverine flooding.

Each of the aforementioned analyses exists for the 10 percent, 2 percent, 1 percent, and 0.1 percent annual chance events, or frequencies, for three different sea level rise scenarios: 9 inches, 21 inches, and 36 inches. In total, results of the above analyses are reported for 12 coastal flooding and sea level rise circumstances. Analyses that evaluate population exposure to coastal and riverine flood impacts also include a fifth frequency: the average monthly highest tide for each sea level rise scenario. This methodology explains the process and approach performed by CRB Analysts to yield the results of each analysis.

4.1 Exposed Persons Analysis

The Exposed Persons Analysis uses the **Structure Exposure Analysis** results to estimate the number of people that reside within residential or mixed use structures located within the inundation area for coastal and riverine floods. The first step to conduct the Exposed Persons Analysis begins by estimating the number of residents per building throughout Boston, using the CRB general building stock and U.S. 2010 Census data provided by census tract. Building populations were estimated per the steps below.

CRB Analysts compiled the results of the analysis and examined them for trends in the number, location, and concentrations of people living in buildings exposed to coastal and riverine flood impacts. Trends are discussed in the Citywide Vulnerability Assessment and the Focus Area assessments; the raw exposure data is located in the **Detailed Results Appendix**.

1. Assign census tracts to structures. CRB analysts used the "Join" tool in ArcGIS to complete this step.
2. Identify the total amount of residential space existing within a census tract. Rather than using the Square Footage Analysis determined in the **Structure Damage and Contents Loss Consequence Analysis**, the entire residential square footage for each building is required for an accurate estimate of population.
3. Divide a structure's residential space by the total amount of residential space within the structure's census tract. This provides a percentage of residential area located within one building.
4. Multiply the percentage of residential area by the total population within the building's census tract. This provides an estimate of the number of people that reside within a building.

4.1.1 Exposure Analysis Limitations

- Results of the Exposed Persons Analysis are dependent upon the accuracy and integrity of the **Structure Exposure Analysis**, and the general building stock.
- The Exposed Persons Analysis likely generates a conservative estimate of the population exposed to coastal and riverine flooding with sea level rise. This analysis does not consider those who work in exposed buildings, or could be affected by disrupted traffic patterns due to flooding.
- U.S. 2010 Census Data was used as the population estimate source in an effort to align with Dr. Atyia Martin's social vulnerability data, which was used to discuss exposed populations with social vulnerability characteristics in the CRB Vulnerability Assessment.
- The Exposed Persons Analysis presents a static representation of the location of residential structures at the time of this report. Future development trends will affect the location and concentration of residential space, which is not reflected within this exposure analysis. Also not reflected in this analysis is expected population growth for Boston, which contributes to the conservative nature of these exposure estimates.

4.2 Shelter Needs Consequence Analysis

Impacted residents may need to shelter if they cannot access their homes due to flooding. Even though the home may not be damaged, people will be displaced if they are evacuated or cannot physically access their property by foot, vehicle, or transit due to flooded roadways and transit systems. This analysis uses flood depths within residential or mixed use structures, and population age and income characteristics to estimate the number of individuals that may require shelter. Low-income individuals, as well as young families and the elderly, are more likely to seek shelter according to FEMA.[28] The population seeking shelter is not assigned a monetary value to avoid double counting benefits associated with Relocation Costs.

4.2.1 Data Sources

- **US Census Bureau American Community Survey (ACS) (2014):** Household income estimates, population counts by age, and persons per household were obtained from the 2014 ACS 5-year estimates. Income and age data are used to weight the displaced population to determine the number of individuals who will seek shelter. Dr. Atyia Martins' Social Vulnerability data was not used in this analysis to ensure that specific data requirements of the methodology are met[29]. Use of such data would imply a level of specificity that cannot currently be known using existing data.
- **Flood depths:** Flood depths for each structure from the **Structure Damage and Contents Loss Exposure Analysis** are used to identify impacted buildings.
- **Structure Population:** The **Exposed Persons Analysis** provides the number of people expected to reside in impacted buildings.

4.2.2 Shelter Needs Analysis Steps

1. Identify Impacted Buildings

Access to an area is assumed to be obstructed at a depth between 6 inches (the typical height of a curb) and 12 inches.[30] For this analysis, any residential unit with a flood depth that equals or exceeds 12

28 HAZUS Flood Technical Manual. FEMA. Pg. 432 Located at: http://www.fema.gov/media-library-data/20130726-1820-25045-8292/hzmh2_1_fl_tm.pdf

29 Specific requirements necessary for the shelter needs analysis include definitions of age factors and income; data related to this information in Dr. Martin's analysis was too broad to confirm.

30 Federal Emergency Management Agency. HAZUS Flood Technical Manual.[web page] Located at: http://www.fema.gov/media-library-data/20130726-1820-25045-8292/hzmh2_1_fl_tm.pdf

inches is expected to cause displacement of residents and create a need for short-term sheltering, at minimum.

2. Displaced Population Likely to Seek Public Shelter

The population within buildings expected to cause resident displacement must be modified to account for the likelihood that an individual may seek out other shelter options such as a hotel or staying with friends or family. Based on the methodology presented in the Hazus-MH Flood Technical Manual, two factors that may impact these choices are income and age (vehicle ownership and other potential factors, such as race or ethnicity, are not considered).[31] Individuals who seek shelter are most likely low-income and/or do not have family in the area; age plays a secondary role, as some individuals may seek shelter even if they have the financial means to do otherwise, such as the young and elderly.[32]

FEMA has developed a constant to adjust for income and age using weight and modification factors (see equation below). Weight and modification factors are based primarily on income, because even though young and elderly families may statistically prefer to use publicly provided shelters, these populations tend to be lower income or on fixed incomes.[33] Default weight and modification factors obtained from the Hazus-MH Flood Technical Manual were used in this analysis, and are provided in Table 13 and Table 14.

$$Constant = (weight\ for\ income * relative\ modificaiton\ factor\ for\ income) + (weight\ for\ age * relative\ modification\ for\ age)$$

For example, the constant for Income Class IM1 and Age Class AM1 is:

$$0.33 = (0.8 * 0.4) + (0.2 * 0.05)$$

Table 15 provides a summary of possible constants.

TABLE 13. WEIGHT FACTORS FOR INCOME AND AGE

Class	Description	Default
IW	Income Weighting Factor	0.8
AW	Age Weighting Factor	0.2

31 Federal Emergency Management Agency. HAZUS Flood Technical Manual. [web page] Located at: http://www.fema.gov/media-library-data/20130726-1820-25045-8292/hzmh2_1_fl_tm.pdf

32 Ibid.

33 Ibid.

TABLE 14. RELATIVE MODIFICATION FACTORS

Class	Description	Default	Default for Communities with 60 percent or More of Households with Income > $35,000
Income			
IM1	Household Income < $10,000	0.4	0.46
IM2	IM2 $10,000 < Household Income < $15,000	0.30	0.36
IM3	$15,000 <Household Income < $25,000	0.15	0.12
IM4	$25,000 < Household Income < $35,000	0.10	0.05
IM5	$35,000 < Household Income	0.05	0.01
Age			
AM1	Population under 16	0.05	-
AM2	Population between 16 and 65	0.20	-
AM3	Population over 65	0.50	-

TABLE 15. CONSTANT FOR EACH COMBINATION OF INCOME AND AGE CLASS

Constant = (IW*IM)+(AW*AM)		
Class	**Default**	**Default for 60 percent HH > 35K**
IM1-AM1	0.33	0.378
IM1-AM2	0.36	0.408
IM1-AM3	0.42	0.468
IM2-AM1	0.25	0.298
IM2-AM2	0.28	0.328
IM2-AM3	0.34	0.388
IM3-AM1	0.13	0.106
IM3-AM2	0.16	0.136
IM3-AM3	0.22	0.196
IM4-AM1	0.09	0.05
IM4-AM2	0.12	0.08
IM4-AM3	0.18	0.14
IM5-AM1	0.05	0.018
IM5-AM2	0.08	0.048

Constant = (IW*IM)+(AW*AM)		
Class	**Default**	**Default for 60 percent HH > 35K**
IM5-AM3	0.14	0.108

3. Determine Distribution of Population by Income and Age Class

Data obtained from the American Community Survey provided the percentage of the population in each income and age class.

4. Determine Sheltering Needs

Sheltering needs can be determined using the following equation provided in the Hazus-MH Flood Technical Manual:

$$People\ using\ shelters = \sum_{k=1}^{5} \sum_{m=1}^{3} (constant_{km} * displaced\ population * percentage\ of\ population\ in\ k\ income\ class * percentage\ of\ population\ m\ age\ class)$$

The constants listed in Table 15 for each combination of income and age classes are used with the total displaced population, percentage of the population in the associated income class, and percentage of the population in the associated age class to obtain a total population that will seek shelter for each income and age class combination. This is completed for each combination of income and age class, and the results are added together to obtain the total population that will seek shelter for a flood scenario.

4.2.3 Assumptions

- Sensitivity analyses conducted by FEMA indicated that small modifications in weight and modification factors had little effect on the estimated shelter needs. It was recommended that analysts use default factors unless there are local statistical data available on populations that use shelters. Thus, it is assumed that FEMA national default income and wage factors are applicable to the project area.
- The entire residential population of a structure is displaced when a structure is flooded.
- Shelter needs do not consider displacement associated with pre-event evacuation, only expected direct flood impact.
- When considering displacement costs, the shelter needs approach is considered to be a double-counting when compared to the relocation approach. The relocation approach assumes that all

displaced individuals will require alternative living quarters, thus capturing the costs of individuals that may opt to go to a shelter. Moreover, the number of individuals that will require shelter after a flood event is likely conservative, since other social vulnerability factors are not considered in the analysis. To account for this benefit duplication, costs associated with sheltering displaced populations are not calculated nor incorporated into the analysis.

4.3 Mental Stress and Anxiety Consequence Analysis

Natural disasters threaten or cause loss of health, social, and economic resources, which leads to psychological distress.[34] Research indicates that individuals who experience significant stressors, such as property damage or displacement, are more likely to experience symptoms of mental illness, Post-Traumatic Stress Disorder (PTSD), and higher levels of stress and anxiety after a disaster.[35] As mental health issues increase after a disaster, it is expected that mental health treatment costs will also increase. The American Red Cross (ARC) estimates that 30 to 40 percent of an impacted population will need mental health assistance after a disaster.[36] Post-Hurricane Sandy research demonstrates that there was a measurable spike in mental stress disorders after the event, including PTSD, anxiety, and depression.[37] As such, FEMA has developed standard values to estimate the treatment costs of mental stress in a post-disaster situation, if a person has personally experienced damage to their residence.

4.3.1 Data Sources

- **Federal Emergency Management Agency's (FEMA) Final Sustainability Benefits Methodology Report (2012):**[38] This report provides a method to calculate costs of avoided mental stress and anxiety treatment.
- **Flood depths:** Flood depths for each structure from the **Structure Damage and Contents Loss Exposure Analysis** are used to identify impacted buildings.

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34 Hobfoll, S.E. 1989. Conservation of resources: A new attempt at conceptualizing stress. American Psychologist. 44:513–524. [PubMed: 2648906].

35 Rhodes, J., Chan, C.,Pacson, C., Rouse, C.E., Waters, M., and E. Fussell. 2010.. The Impact of Hurricane Katrina on the mental and physical health of low-income parents in New Orleans. Am J Orthopsychiatry. April; 80(2): 237-247.

36 Welker, Catherine. 2011. American Red Cross Liaison Officer to FEMA Headquarters Disaster Services. Personal correspondence, December 6.

37 Beth Israel Medical Center data indicate a 69 percent spike in psychiatric visits in November 2012. Healthcare Quality Strategies Inc. reviewed Medicare claims before and after Hurricane Sandy in select communities in New Jersey and found that PTSD was up 12.2 percent, anxiety disorders were up 7.8 percent, and depression or proxy disorders were up 2.8 percent.

38 Federal Emergency Management Agency. Final Sustainability Benefits Methodology Report. August 23, 2012.

- **Structure Population:** The **Exposed Persons Analysis** provides the number of people expected to reside in impacted buildings.

4.3.2 Analysis Steps

Mental health treatment costs can be based on three factors: cost, prevalence, and course. Prevalence is the percentage of people who experience mental health problems after a disaster event, and course is the rate at which mental health symptoms reduce or increase over time. Cost is simply the cost of treatment to those who seek it.

1. Determine Prevalence Rate and Course

FEMA's Final Sustainability Benefits Methodology Report[39] uses prevalence percentages and mental health expenses from Schoenbaum (2009) to derive a standard value for mental stress and anxiety costs. Prevalence percentages are adjusted over different time periods. Mild to moderate impacts will reduce over time as treatment is provided, and severe mental health problems may persist much longer, possibly never being fully resolved.[40] For this reason, mild to moderate mental health prevalence percentages reduce over time, while severe mental health prevalence percentages remain consistent after a disaster. Findings from Kessler et al. (2008) support this trend, reporting increasing rates of PTSD and severe mental health issues between six months after a hurricane and approximately one year after.[41] It is possible, if left untreated, that PTSD and severe mental illness can become more entrenched over time, while mild or moderate mental illness symptoms attenuate.[42] Table 16 provides a summary of prevalence considering course over four different lengths of time.[43] It is important to note that this methodology only captures mental health impacts for the first 30 months because evidence of prevalence rates after this time period is not currently available.

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39 FEMA. 2012. Final Sustainability Benefits Methodology Report. August 23.

40 Schoenbaum, Michael; Butler, Brittany; Kataoka, Sheryl; Norquist, Grayson; Springgate, Benjamin; Sullivan, Greer; Duan, Naihua; Kessler, Ronald; and Kenneth Wells. 2009. Promoting Mental Health Recovery After Hurricanes Katrina and Rita: What Can Be Done at What Cost. Archives of General Psychiatry, Vol. 66, #8, August.

41 Kessler RC, Galea S, Gruber MJ, Sampson NA, Ursano RJ, and S. Wessely. 2008. Trends in mental illness and suicidality after Hurricane Katrina. Molecular Psychiatry. 13:374–384.

42 Rhodes, J., Chan, C.,Pacson, C., Rouse, C.E., Waters, M., and E. Fussell. 2010.. The Impact of Hurricane Katrina on the mental and physical health of low-income parents in New Orleans. Am J Orthopsychiatry. April; 80(2): 237-247.

43 FEMA. 2014. Updated Social Benefits Methodology Report. December 18.

TABLE 16. PREVALENCE OF MENTAL HEALTH ISSUES AFTER A DISASTER

Time after Disaster	Severe	Mild/Moderate
7-12 months	6 percent	26 percent
13-18 months	7 percent	19 percent
19-24 months	7 percent	14 percent
25-30 months	6 percent	9 percent

Source: FEMA Updated Social Sustainability Methodology Report

2. Determine Cost

Schoenbaum provides an estimate of treatment costs in an ideal scenario where all needs are met. FEMA argues that treatment costs from the study must be adjusted to consider only those with mental health problems who will actually seek out treatment (41 percent).[44] According to Wang et al, of the 41 percent, 16 percent receive adequate care and 25.1 percent receive inadequate care. FEMA uses the following steps to adjust total treatment costs from Schoenbaum for percentage of individuals who seek treatment and for prevalence.

$$Cost\ per\ person\ seeking\ treatment = Treatment\ cost\ per\ person^{45} * 0.41 * prevalence$$

For example,

$$\$623.63^{46} = (\$5,835.95 * 0.16) + (\$5,835.95 * 0.25.1) * 0.26$$

This methodology is applied to each length of time, adjusting for prevalence. The values provided by FEMA's Social Benefits Methodology Report have been normalized using the Consumer Pricing Index (CPI) Inflation Calculator,[47] and the costs for both severe and mild/moderate mental health problems over each time period are added together to provide a total treatment cost of $ 2,707 for 30 months.

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44 Wang, Philip S., MD, DrPH; Lane, Michael, MS; Olfson, Mark, MD, MPH; Pincus, Harold A., MD; Wells, Kenneth B., MD, MPH; Kessler, Ronald C., PhD. 2005. Twelve-Month Use of Mental Health Services in the United States: Results from the National Comorbidity Survey Replication. Archives of General Psychiatry, v. 62, June.

A., MD; Wells, Kenneth B., MD, MPH; and Ronald C. Kessler, PhD. 2005. Twelve-Month Use of Mental Health Services in the United States: Results from the National Comorbidity Survey Replication. Archives of General Psychiatry, v. 62, June.

45 Schoenbaum, Michael; Butler, Brittany; Kataoka, Sheryl; Norquist, Grayson; Springgate, Benjamin; Sullivan, Greer; Duan, Naihua; Kessler, Ronald; Wells, Kenneth. 2009. Promoting Mental Health Recovery After Hurricanes Katrina and Rita: What Can Be Done at What Cost. Archives of General Psychiatry, Vol. 66, #8, August 2009.

46 Value not normalized to current dollars.

47 U.S. Bureau of Labor Statistics. Undated. CPI Inflation Calculator. [web page] Located at: http://www.bls.gov/data/inflation_calculator.htm.

Table 17 provides a summary of treatment costs in current dollars. These values are national figures and do not take into consideration local costs.

TABLE 17. COST OF TREATMENT[48] AFTER A DISASTER (30 MONTH DURATION), PER PERSON EXPECTED TO SEEK TREATMENT

Time after Disaster	Severe	Mild/Moderate	Total per person
7-12 months	$ 220.00	$ 691.27	$ 911.27
13-18 months	$ 256.66	$ 451.98	$ 708.64
19-24 months	$ 256.66	$ 372.22	$ 628.88
25-30 months	$ 218.89	$ 239.28	$ 458.17
Total			**$ 2,707**

Source: FEMA Updated Social Sustainability Methodology Report

3. Identify Impacted Population

Because the cost of treatment incorporates prevalence and course factors, the total number of residents in flooded buildings are considered impacted and included in the total population that may seek treatment. The cost of treatment per person over a 30-month period ($2,706.96) is applied to this population to determine treatment costs for mental stress and anxiety.

4.3.3 Assumptions

- Research analysis is limited to 30 months after a disaster. As such, estimated losses avoided are limited to this time period. Mental health avoided losses beyond two and a half years after a disaster, though expected, are not valued in this analysis.
- Benefits are calculated for only 41 percent of the impacted population because research indicates that only that portion of the population with mental health issues can be expected to seek treatment. This significantly lowers the calculated treatment costs and does not consider the full costs to society.
- Population growth is not considered in this analysis.
- These values are national figures and do not take local costs into consideration.

48 Costs normalized to 2015 dollars using the CPI calculator located at: http://data.bls.gov/cgi-bin/cpicalc.pl?cost1=623.63&year1=2008&year2=2015

4.4 Lost Productivity Consequence Analysis

Work productivity can be lost due to mental illness as described in research on the impact of psychiatric disorders on work loss days (Kessler and Frank, 1997). One report found that the average prevalence of psychiatric work loss days[49] is six days per month per 100 workers, and work cutback days[50] is 31 days per month per 100 workers.[51] Further research conducted by Kessler et al (2008) found that respondents with serious mental illness will experience a $16,306 reduction in a 12-month earning period compared to respondents without mental illness, and a study of 19 countries by the World Health Organization showed a lifetime 32 percent reduction in earnings for respondents with mental illness.[52] Historical impacts indicate that mental health issues will increase after a disaster, and this, paired with research related to lost productivity due to mental illness, indicates that economic productivity can be impacted by an increase in mental health issues post-disaster.[53]

4.4.1 Data Sources

- **Federal Emergency Management Agency's (FEMA) Final Sustainability Benefits Methodology Report (2012):**[54] This report provides a method to calculate benefits related to avoided lost productivity.
- **US Census Bureau American Community Survey (2014):** The average number of workers per household and persons per household are used to determine the number of impacted workers.
- **Flood depths:** Flood depths for each structure from the **Structure Damage and Contents Loss Exposure Analysis** are used to identify impacted buildings.
- **Structure Population:** The **Exposed Persons Analysis** provides the number of people expected to reside in impacted buildings.

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49 A psychiatric work loss day is the complete inability to work or perform normal activities due to mental illness or its treatment.

50 Work cutback days is the reduced work activity due to mental illness or its treatment.

51 1: Kessler RC, Frank RG. The impact of psychiatric disorders on work loss days. Psychol Med. 1997 Jul; 27(4):861-73. PubMed PMID: 9234464.

52 Levinson, et al. 2010. Associations of Serious Mental Illness with Earnings: Results from the WHO World Mental Health Surveys. British Journal of Psychiatry. August; 197(2): 114–121. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2913273

53 Insel, Thomas. Assessing the Economic Costs of Serious Mental Illness. American Journal of Psychiatry. 165:6 June 2008. / Kessler et al. Individual and Societal Effects of Mental Disorders on Earnings on the United States: Results from the National Comorbidity Survey Replication. American Journal of Psychiatry. 165:6. June 2008.

54 Federal Emergency Management Agency. Final Sustainability Benefits Methodology Report. August 23, 2012.

4.4.2 Analysis Steps

1. Determine Value of Work Productivity

CRB Analysts researched several sources of literature related to lost productivity due to mental illness, and focused on a study in which Levinson et al (2010)[55] conducted research using the World Health Organization's Mental Health Surveys conducted in 19 countries. The study found that individuals in the United States with mental health illnesses experience as much as a 25.5 percent reduction in earnings. The national average for employment compensation in March 2015 was $33.49 per hour.[56] This, multiplied by the average number of hours worked per day (6.9),[57] produces a daily U.S. value of $231.08. Thus, a 25.5 percent reduction in earnings would equal a loss of $58.90 daily, or $1,767.77 monthly.

2. Determine Prevalence Rates

Post-disaster time periods are based on prevalence factors presented in Table 16 in the **Mental Stress and Anxiety Consequence Analysis**. The number of months of each time period after the disaster (Column 1 of Table 18) is applied to the monthly productivity loss ($1,767.77) to determine possible lost productivity for that time period. Prevalence factors from Schoenbaum (2009) are used to adjust productivity loss, as only a portion of the population will experience mental health impacts post-disaster. The prevalence factor is based on severe mental health issues because there is insufficient literature to document the impacts of mild/moderate mental health issues on productivity.[58]

TABLE 18. 30-MONTH LOSS IN PRODUCTIVITY PER WORKER, ATTRIBUTED TO SEVERE MENTAL HEALTH

Time after Disaster	Potential Productivity Loss due to Severe Mental Illness	Prevalence Factor in Impacted Population	Proportionate Productivity Loss Share per Worker in Impacted Population
1-12 months (12 mo.)	$21,213	6 percent	$1,273
13-18 months (6 mo.)	$10,607	7 percent	$742
19-24 months (6 mo.)	$10,607	7 percent	$742

55 Levinson, et al. 2010. Associations of Serious Mental Illness with Earnings: Results from the WHO World Mental Health Surveys. British Journal of Psychiatry. August; 197(2): 114–121. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2913273

56 Employer Costs for Employee Compensation. March 2015. United States Department of Labor, Bureau of Labor Statistics.

57 Average week hours of overtime of all employees. Web page. Located at: http://www.bls.gov/news.release/empsit.t18.htm

58 FEMA. 2014. Updated Social Benefits Methodology Report. December 18.

Time after Disaster	Potential Productivity Loss due to Severe Mental Illness	Prevalence Factor in Impacted Population	Proportionate Productivity Loss Share per Worker in Impacted Population
25-30 months (6 mo.)	$10,607	6 percent	$636
Total Productivity Loss per Worker			$3,394

For example,

$$(\$1{,}767.77\ per\ month * 12\ months) * 6\ percent = \$1{,}273$$

3. Identify Impacted Population

As prevalence is considered in the annual cost of lost productivity, the total population in residential and mixed use buildings that experience flooding are considered impacted for this analysis. The average number of persons per household (2.36) were used to determine number of households in Boston from population data. The average number of workers per household in Boston (1.4 workers) is applied to the number of households impacted to determine the number of wage earning residents who will experience flooding. The total lost productivity share per worker for 30 months ($3,394) is applied to the number of wage-earning residents who will experience flooding to value productivity losses avoided.

4.4.3 Assumptions

- Value is provided for the first 30 months only because there is insufficient literature available to analyze longer periods of time.
- Prevalence rates are based on severe mental issues because there is insufficient literature related the impacts of mild or moderate mental health problems on work productivity. Thus, results are considered conservative.
- Population growth is not considered in this analysis.
- Values are national figures and do not take into consideration local costs.

5 ECONOMY

Impacts to people, structures, infrastructure, and general interruption of normal activity as a result of climate-related hazards can also disrupt the broader Boston economy. Severe impacts can have regional, national, and even international consequences. As a result, CRB has sought to capture the potential impacts of business interruption within Boston due to coastal and riverine flooding with sea level rise. The business interruption consequence analysis, described below, uses the restoration time per building developed in the **Displacement Consequence Analysis** to estimate expected losses of sales and revenues (output loss), employment compensation, and jobs post-flood.

The business interruption analysis calculates direct output losses (sales and revenues) for the 10 percent, 1 percent, and 0.1 percent annual chance events, or frequencies, for three different sea level rise scenarios: 9 inches, 21 inches, and 36 inches. These losses are annualized and modeled with IMPLAN economic input-output software to estimate indirect and induced economic losses expected throughout Suffolk County. As such, results are presented as annualized for each sea level rise scenario only (individual results values are not presented). This methodology explains the process and approach performed by CRB Analysts to yield the results of each analysis.

Direct Impacts	Indirect Impacts	Induced Impacts
• The loss of sales and revenues (output), employment compensation, and employment due to business interruption. • Business interruption is calculated using restoration time.	• The impact of local industries buying goods and services from other local industries. The cycle of spending works its way backward through the supply chain until all money leaks from the local economy, such as through imports.	• The response by an economy to an initial change (direct effect) that occurs through re-spending of income received. Employee compensation funds are recirculated through household spending patterns.

FIGURE 4. ECONOMIC IMPACT DEFINITIONS

5.1 Business Interruption Consequence Analysis

The Business Interruption Consequence Analysis models existing economic relationships within Suffolk County, and the expected impacts to those relationships in a post-flood situation. These economic impacts are based on expected business interruption time, which is derived from restoration costs (refer to **Displacement Consequence Analysis** for an explanation of how business interruption times are calculated). Business interruption time can be used to calculate the expected direct output losses (sales and revenues) for an economic industry. Direct output losses are imported into input-output modeling software to estimate the effects of sales and revenues loss on relationships with other industries and spending patterns in the economy (generating indirect and induced output losses). While direct output losses are based on structures within Boston expected to flood, the economic modeling software models economic relationships throughout Suffolk County. Thus, business interruption consequence analysis results are expected economic impacts to the County economy. No broader effects (such as metropolitan area, state, national, or international) are considered. Due to this and other reasons described below, results of this analysis are expected to be conservatively low.

5.1.1 Data Sources

- **Hazus 2.1 Flood Technical Manual (TM), Direct Economic Losses Chapter 14** provides the principle calculation used to determine output loss.
- **Restoration time** identified through the **Displacement Consequence Analysis**.
- **Flood depths:** Flood depths for each structure from the **Structure Damage and Contents Loss Exposure Analysis** are used to identify impacted buildings.
- **2014 IMPLAN County Data for Suffolk County**. IMPLAN incorporates economic data from many sources, including the U.S. Bureau of Economic Analysis (BEA), the U.S. Bureau of Labor Statistics (BLS), and the U.S. Census Bureau. The dataset used provides localized economic industry data by zip code within Suffolk County, including output values (sales and revenues), labor income (employee and proprietor compensation), value added (contribution to national Gross Domestic Product), and employment (jobs).

5.1.2 Approach

The approach to calculate expected business interruption as a result of flood impacts is as follows:

1. Map PTYPEs to IMPLAN economic industries using a crosswalk, similar to the process used to map PTYPEs to Hazus occupancy classes described in the **Structure Damage and Contents Loss Consequence Analysis**. Due to the level of detail provided in the PTYPE occupancy descriptions, the crosswalk rarely identifies singular relationships between a PTYPE and an IMPLAN economic industry. To account for this, CRB analysts developed groups of PTYPES and economic industries that are related; these groupings varied by zip code, depending on the PTYPES and economic industries present within the area. Table 19 provides example groups for offices and retail space. CRB analysts developed one crosswalk per zip code in Suffolk County.

TABLE 19. EXAMPLE BUSINESS INTERRUPTION GROUPS – RETAIL AND COMMERCIAL BUILDINGS

Group	IMPLAN Code	IMPLAN Description	Ptype	Ptype Description
Retail	397	Retail - Furniture and home furnishings stores	319	STRIP CENTER /STORES
	398	Retail - Electronics and appliance stores	320	RETAIL /WHSL /SERVICE
	399	Retail - Building material and garden equipment and supplies stores	325	RETAIL STORE DETACHED
	400	Retail - Food and beverage stores	390	COMMERCIAL LAND
	401	Retail - Health and personal care stores	391	COM LAND (SECONDARY)
	402	Retail - Gasoline stores	950	RETAIL CONDO: EXEMPT
	403	Retail - Clothing and clothing accessories stores	357	RETAIL CONDO
	404	Retail - Sporting goods, hobby, musical instrument and book stores		
	405	Retail - General merchandise stores		
	406	Retail - Miscellaneous store retailers		
	407	Retail - Nonstore retailers		
	443	General and consumer goods rental except video tapes and discs		
	395	Wholesale Trade		
	396	Retail - Motor vehicle and parts dealers		
Commercial	415	Couriers and messengers	13	RES /COMMERCIAL USE
	427	Wired telecommunications carriers	25	RC: ONE RES UNIT
	432	Internet publishing and broadcasting and web search portals	26	RC: TWO RES UNITS
	437	Insurance carriers	27	RC: THREE RES UNITS
	438	Insurance agencies, brokerages, and related activities	31	COM /RES MULTI-USE
	445	Commercial and industrial machinery and equipment rental and leasing	340	OFFICE (ATTACHED)
	447	Legal services	343	OFFICE 1-2 STORY
	448	Accounting, tax preparation, bookkeeping, and payroll services	344	OFFICE 3-9 STORY

2. Calculate total average output per square foot for a group. CRB analysts added all square footage of PTYPEs in a group, and all output data for economic industries within a group, and developed an average annual and daily output per square foot for a group.

$$Total\ Average\ Ouput\ per\ Square\ Foot = Group\ Total\ Economic\ Output\ /\ Group\ Total\ Square\ Footage$$

3. Identify impacted structures within the various groups. Structures that are expected to incur restoration time (as identified through the **Displacement Consequence Analysis**) are eligible for direct business interruption consequences. The area of impacted square footage is necessary from eligible structures (those expected to incur restoration time); if the flood depth within a structure is less than 10 feet, it is assumed that only the first floor is flooded, and thus the square footage of the footprint is considered.

4. Calculate output losses. Hazus Flood TM provides calculations to evaluate the expected loss of industry output due to business interruptions; this calculation is presented below. CRB analysts made minor revisions to the original calculation, discussed in the Assumptions section.

$$Structure\ Output\ Loss = (Floor\ Area\ of\ Impacted\ Building) * (Group\ Output\ per\ SF\ per\ Day) * (Structure\ Restoration\ Time)$$

5. Distribute direct output losses among grouped economic industries. In order to input output losses into the IMPLAN software, output losses for structures within a group have to be distributed among the economic industries within the group. This is done by using each industry's contributing output and assigning a weighting factor based on the industry's contribution to the group's total output. The weighting factor determines how much of the group's total output loss is assigned to an industry (

6. Table 20). The reason for developing a weighting factor, rather than distributing total output loss equally across all contributing industries, is because each industry is not equally prevalent in the study area. Below is an example of this approach.

TABLE 20. EXAMPLE WEIGHTING FACTORS AS DEMONSTRATED BY THE RESTAURANT GROUP

Economic Industry	Annual Industry Output	Output Weighting Factor
Full-Service Restaurants	$388,000,000	0.53
Limited-Service Restaurants	$177,000,000	0.24
All other food and drinking places	$171,000,000	0.23
Total	$736,000,000	-

$$Industry\ Output\ Loss = Total\ Group\ Output\ Loss * Output\ Weighting\ Factor$$

So, if the impacted structures belonging to the Restaurant Group have a total output loss of $10,000,000, the output loss would be distributed to each industry as displayed below in Table 21.

TABLE 21. EXAMPLE OUTPUT LOSS DISTRIBUTION AMONG RESTAURANT INDUSTRIES

Economic Industry	Output Weighting Factor	Output Loss per Industry
Full-Service Restaurants	0.53	$5,300,000
Limited-Service Restaurants	0.24	$2,400,000
All other food and drinking places	0.23	$2,300,000
Total Group Output Loss	-	$10,000,000

7. Input direct output losses per industry in IMPLAN software, and model indirect and induced impacts within a zip code throughout the Suffolk County economy. IMPLAN software uses a combination of social accounting matrices and economic multipliers to estimate the result of changes or activities. The software reports estimated direct, indirect, and induced impacts for economic output, labor income, value added, and employment.

5.1.3 Assumptions and Avoidance of Benefit Duplication

Because there are many assumptions associated with the business interruption analysis, assumptions are organized by three categories: Crosswalk Development, Output Loss Calculations, and IMPLAN Modeling.

- Crosswalk Development
    - The crosswalk rarely identifies one to one relationships between a PTYPE and an IMPLAN economic industry. Instead, analysts must make assumptions and aggregate economic industries and PTYPEs into groups. Once such groups are formed, analysts assign each group an average value of output (sales and revenues) per square foot for the group based on local data.
    - In order to estimate Boston's expected business interruption consequences at a neighborhood level, the zip code is the basis of the crosswalk. CRB Analysts assumed

that average output values per square foot within a zip code are generally appropriate for buildings located within that zip code.

- Output Loss Calculations
    - Distributing output loss results amongst economic industries within a group using weight factors is necessary because it is inappropriate to assume that each economic industry within a family is equally prevalent in the study area. For example, it is not fair to assume that a 2,500 square foot computer technology store has the same output as a clothing store of the same size, even though both industries are in the retail family. By weighting industries based on actual output per square foot within the zip code, the expected damage to each industry is appropriately modified to reflect the approximate presence of the industry in the local economy.
    - Output loss calculations are based solely upon direct physical damages to buildings. As a result, results shown do not provide a logical connection to significant disaster impacts to services such as transportation or utilities. In addition, disruption is likely to occur to the entire structure for a period of time (for several reasons, to include power outage, MEP damage that impacts the entire structure, molding or other issues, and more), as opposed to only directly impacted floors. There is no currently available reliable research that could be located to estimate these impacts, and so they have been excluded from the evaluation. This is a limitation of the analysis and likely yields conservative results.
    - If the expected flood depth within the structure is less than ten feet, the building footprint is used to calculate output loss. In the case that expected flood depth is more than ten feet, CRB analysts assumed that some portion of the second story of the structure was inundated, and the square footage for the first two floors is considered.
    - Mixed use structures are assumed to have all non-residential space located on the lowest floors. See Section 3.0 Property for more on this.
    - The original output loss calculation provided by the Earthquake Technical Manual incorporates a recapture factor, which represents output losses that can be recouped to some extent by working overtime after an event. These recapture factors have not been included in the output loss calculation. The analysis assumes that, as soon as a business relocates or reopens after a disaster, it is able to return immediately to pre-storm output. Recapture factors are not appropriate for use because they do not consider opportunity costs.

- IMPLAN Modeling: IMPLAN input-output software is used in the analysis to identify indirect and induced economic losses that result from business interruption, and therefore serves to model the economic relationships present within the New York County economy. The below assumptions must be considered when observing the IMPLAN results:
  - The results display the economic impacts expected within Suffolk County as a result of expected output loss in a zip code. Therefore, these impacts are considered to be conservative, as the local economy for the study area has economic linkages that impact areas far beyond Suffolk County.
  - IMPLAN does not account for price elasticities or changes in consumer/industry behavior based on a direct effect, such as changes in spending patterns within sectors not related directly to activity changes.
  - Seasonal variation in economic output of various sectors included in the analysis was not considered due to data limitations. Results are presented in 2016 dollars.

6 CONSEQUENCE ANALYSIS DATA

CRB Analysts imported the results of the CRB consequence analyses into ArcGIS to facilitate data transfer and use. The consequence analysis results dataset is a point-file dataset, and is meant to accompany the general building stock. Note that any changes to the CRB building footprint dataset or the general building stock should be carried over into consequence analysis results during future evaluations in order to maintain data consistency and improve results fidelity over time. Table 22 provides a list of the attributes for one sea level rise scenario; these attributes are repeated within the ArcGIS data for each sea level rise scenario and are appropriately labeled as such.

TABLE 22. CRB CONSEQUENCE ANALYSIS ATTRIBUTES AND DESCRIPTION WITHIN EACH STUDIED SEA LEVEL RISE SCENARIO

Attribute	Field Name	Description
CRB ID	CRB_BLDGID	Building ID developed by CRB analysts to facilitate data management and QAQC.
Latitude	Latitude	Reference point of the building centroid.
Longitude	Longitude	Reference point of the building centroid.
PTYPE	TempPTYPE	Building use.
10% Flooded	Flooded_9in_10per	Notes if the building is located within the inundation area of the 10% flood extent.
10% Flood Depth	NT9in_10per_AEP_Flood_Depth	The expected flood depth in the structure for the 10% flood event. Determined by subtracting water surface elevations from the building elevation.
10% Percent Building Loss	NT9in_10per_AEP_Building_Loss	Percent building loss to determine the damage state for the 10% flood event. Based on occupancy type and flood depth.
10% Building Damage Costs	NT9in_10per_AEP_Building_Loss2	Expected damage costs for the structure for the 10% flood event.
10% Percent Contents Loss	NT9in_10per_AEP_Contents_Loss	Percent contents loss for the structure for the 10% flood event. Based on occupancy type and flood depth.
10% Building Contents Loss	NT9in_10per_AEP_Contents	Expected contents losses for the structure for the 10% flood event.
10% Days Relocation	NT9in_10per_AEP_Days_Relocation	Expected relocation time for the structure for the 10% flood event, based on occupancy type and flood depth.

Attribute	Field Name	Description
10% Days Relocation Cost	NT9in_10per_AEP_Relocation_Cost	Expected relocation costs for structure occupant and business relocation for the 10% flood event.
10% Restoration Time	NT9in_10per_Days_Restoration	Method 1 to estimate restoration time for the 10% flood event.
10% ELOF Test	ELOF_TEST_10per_AEP	Method 2 to estimate restoration time for the 10% flood event. Used in the CRB Analysis.
10% Business Interruption SF	NT9in_10per_AEP_ELOF_SF	Square footage analysis to determine business interruption results for the 10% flood event.
10% ELOF Impact	NT9in_10per_ELOF_Impact	Restoration Time multiplied by the Business Interruption square footage for the 10% flood event.
2% Flooded	NT9in_2per_flooded	Notes if the building is located within the inundation area of the 2% flood extent.
2% Flood Depth	NT9in_2per_AEP_flood_depth	The expected flood depth in the structure for the 2% flood event. Determined by subtracting water surface elevations from the building elevation.
2% Percent Building Loss	NT9in_2per_AEP_per_Building_Loss	Percent building loss to determine the damage state for the 2% flood event. Based on occupancy type and flood depth.
2% Building Damage Costs	NT9in_2per_AEP_Building	Expected damage costs for the structure for the 2% flood event.
2% Percent Contents Loss	NT9in_2per_AEP_per_Contents_Loss	Percent contents loss for the structure for the 2% flood event. Based on occupancy type and flood depth.
2% Building Contents Loss	NT9in_2per_AEPContents	Expected contents losses for the structure for the 2% flood event.
2% Days Relocation	NT9in_2per_AEP_Relocation	Expected relocation time for the structure for the 2% flood event, based on occupancy type and flood depth.
2% Days Relocation Cost	NT9in_2per_AEP_Relocation_Cost2	Expected relocation costs for structure occupant and business relocation for the 2% flood event.
2% Restoration Time	NT9in_2per_Days_Restoration	Method 1 to estimate restoration time for the 2% flood event.
2% ELOF Test	ELOF_TEST_2per_AEP	Method 2 to estimate restoration time for the 2% flood event. Used in the CRB Analysis.
2% Business Interruption SF	NT9in_2per_AEP_ELOF_SF	Square footage analysis to determine business interruption results for the 2% flood event.

Attribute	Field Name	Description
2% ELOF Impact	NT9in_2per_ELOF_Impact	Restoration Time multiplied by the Business Interruption square footage for the 2% flood event.
1% Flooded	NT9in_1per_flooded	Notes if the building is located within the inundation area of the 1% flood extent.
1% Flood Depth	NT9in_1per_AEP_flood_depth	The expected flood depth in the structure for the 1% flood event. Determined by subtracting water surface elevations from the building elevation.
1% Percent Building Loss	NT9in_1per_AEP_per_Building_Loss	Percent building loss to determine the damage state for the 1% flood event. Based on occupancy type and flood depth.
1% Building Damage Costs	NT9in_1per_AEP_Building	Expected damage costs for the structure for the 1% flood event.
1% Percent Contents Loss	NT9in_1per_AEP_per_Contents_Loss	Percent contents loss for the structure for the 1% flood event. Based on occupancy type and flood depth.
1% Building Contents Loss	NT9in1per_AEP_Contents	Expected contents losses for the structure for the 1% flood event.
1% Days Relocation	NT9in_1per_AEP_Days_Relocation	Expected relocation time for the structure for the 1% flood event, based on occupancy type and flood depth.
1% Days Relocation Cost	NT9in_1per_AEP_Relocation_Cost	Expected relocation costs for structure occupant and business relocation for the 1% flood event.
1% Restoration Time	NT9in_1per_Days_Restoration	Method 1 to estimate restoration time for the 1% flood event.
1% ELOF Test	ELOF_TEST_1per_AEP	Method 2 to estimate restoration time for the 1% flood event. Used in the CRB Analysis.
1% Business Interruption SF	NT9in_1per_AEP_ELOF_SF	Square footage analysis to determine business interruption results for the 1% flood event.
1% ELOF Impact	NT9in_1per_ELOF_Impact	Restoration Time multiplied by the Business Interruption square footage for the 1% flood event.
0.1% Flooded	NT9in_01per_flooded	Notes if the building is located within the inundation area of the 0.1% flood extent.
0.1% Flood Depth	NT9in_01per_AEP_Flood_Depth	The expected flood depth in the structure for the 0.1% flood event. Determined by subtracting water surface elevations from the building elevation.

Attribute	Field Name	Description
0.1% Percent Building Loss	NT9in_01per_AEP_per_Building_Loss	Percent building loss to determine the damage state for the 0.1% flood event. Based on occupancy type and flood depth.
0.1% Building Damage Costs	NT9in_01per_AEP_Building	Expected damage costs for the structure for the 0.1% flood event.
0.1% Percent Contents Loss	NT9in_01per_AEP_per_Contents_Loss	Percent contents loss for the structure for the 0.1% flood event. Based on occupancy type and flood depth.
0.1% Building Contents Loss	NT9in_01per_AEP_Contents	Expected contents losses for the structure for the 0.1% flood event.
0.1% Days Relocation	NT9in_01per_AEP_Days_Relocation	Expected relocation time for the structure for the 0.1% flood event, based on occupancy type and flood depth.
0.1% Days Relocation Cost	NT9in_01per_AEP_Relocation_Cost	Expected relocation costs for structure occupant and business relocation for the 0.1% flood event.
0.1% Restoration Time	NT9in_01per_Days_Restoration	Method 1 to estimate restoration time for the 0.1% flood event.
0.1% ELOF Test	ELOF_TEST_01per_AEP	Method 2 to estimate restoration time for the 0.1% flood event. Used in the CRB Analysis.
0.1% Business Interruption SF	NT9in_01per_AEP_ELOF_SF	Square footage analysis to determine business interruption results for the 0.1% flood event.
0.1% ELOF Impact	NT9in_01per_ELOF_Impact	Restoration Time multiplied by the Business Interruption square footage for the 0.1% flood event.
10% Mental Stress and Anxiety	NT10per_AEP_Mental_Stress	Expected treatment costs of mental stress for residents of structures impacted by the 10% flood event.
10% Lost Productivity	NT10per_AEP_Lost_Productivity	Expected costs of lost work days due to mental stress related to 10% flood event impacts.
10% Shelter Needs	NT10per_AEP_Shelter_Needs	Number of residents within buildings impacted by the 10% event expected to require shelter.
2% Mental Stress and Anxiety	NT2per_AEP_Mental_Stress	Expected treatment costs of mental stress for residents of structures impacted by the 2% flood event.
2% Lost Productivity	NT2per_AEP_Lost_Productivity	Expected costs of lost work days due to mental stress related to 2% flood event impacts.
2% Shelter Needs	NT2per_AEP_Shelter_Needs	Number of residents within buildings impacted by the 2% event expected to require shelter.

Attribute	Field Name	Description
1% Mental Stress and Anxiety	NT1per_AEP_Mental_Stress2	Expected treatment costs of mental stress for residents of structures impacted by the 1% flood event.
1% Lost Productivity	NT1per_AEP_Lost_Productivity	Expected costs of lost work days due to mental stress related to 1% flood event impacts.
1% Shelter Needs	NT1per_AEP_Shelter_Needs	Number of residents within buildings impacted by the 1% event expected to require shelter.
0.1% Mental Stress and Anxiety	NT01per_AEP_Mental_Stress	Expected treatment costs of mental stress for residents of structures impacted by the 0.1% flood event.
0.1% Lost Productivity	NT01per_AEP_Lost_Productivity	Expected costs of lost work days due to mental stress related to 0.1% flood event impacts.
0.1% Shelter Needs	NT01per_AEP_Shelter_Needs	Number of residents within buildings impacted by the 0.1% event expected to require shelter.
10% Annualized Building Damage	NT10per_Ann_Bldg_	Annualized building damage expected for the 10% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
10% Annualized Contents Loss	NT10per_Ann_Contents	Annualized contents and inventory loss expected for the 10% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
10% Annualized Displacement	NT10per_Ann_Displacement_	Annualized displacement costs expected for the 10% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
10% Annualized Mental Stress	NT10per_Ann_Mental_Stress	Annualized mental stress treatment costs expected for the 10% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
10% Annualized Lost Productivity	NT10per_Ann_Lost_Productivity	Annualized lost productivity expected for the 10% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
2% Annualized Building Damage	NT2per_Ann_Bldg	Annualized building damage expected for the 2% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
2% Annualized Contents Loss	NT2per_Ann_Contents	Annualized contents and inventory loss expected for the 2% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.

Attribute	Field Name	Description
2% Annualized Displacement	NT2per_Ann_Displacement	Annualized displacement costs expected for the 2% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
2% Annualized Mental Stress	NT2per_Ann_Mental_Stress	Annualized mental stress treatment costs expected for the 2% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
2% Annualized Lost Productivity	NT2per_Ann_Lost_Productivity	Annualized lost productivity expected for the 2% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
1% Annualized Building Damage	NT1per_Ann_Bldg	Annualized building damage expected for the 1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
1% Annualized Contents Loss	NT1per_Ann_Contents	Annualized contents and inventory loss expected for the 1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
1% Annualized Displacement	NT1per_Ann_Displacement	Annualized displacement costs expected for the 1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
1% Annualized Mental Stress	NT1per_Ann_Mental_Stress	Annualized mental stress treatment costs expected for the 1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
1% Annualized Lost Productivity	NT1per_Ann_Lost_Productivity	Annualized lost productivity expected for the 1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
0.1% Annualized Building Damage	NT01per_Ann_Bldg	Annualized building damage expected for the 0.1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
0.1% Annualized Contents Loss	NT01per_Ann_Contents	Annualized contents and inventory loss expected for the 0.1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
0.1% Annualized Displacement	NT01per_Ann_Displacement	Annualized displacement costs expected for the 0.1% annual chance event. Calculated by

Attribute	Field Name	Description
		multiplying expected one-time damage costs by the probability of occurrence.
0.1% Annualized Mental Stress	NT01per_Mental_Stress	Annualized mental stress treatment costs expected for the 0.1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
0.1% Annualized Lost Productivity	NT01per_Lost_Productivity	Annualized lost productivity expected for the 0.1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
Total Annualized Structure and Contents	Total_Annualized_Structure_and_Contents_Losses	Total annualized structure and contents losses expected for the sea level rise scenario. Developed by adding expected annualized structure and contents losses for the four frequencies analyzed.
Total Annualized Loss of Service	Total_Annualized_Loss_of_Service__Function	Total annualized loss of service expected for the sea level rise scenario. Developed by adding expected annualized loss of service values for the four frequencies analyzed.
Total Annualized Structure, Content, and Relocation Costs	Total_Annualized_Structure_Content_and_Relocation_Losses	Total annualized structure, contents, and relocation losses expected for the sea level rise scenario (total property consequences). Developed by adding expected property consequences for the four frequencies analyzed.
Total Annualized Relocation	Total_Annualized_Relocation	Total annualized relocation costs expected for the sea level rise scenario. Deveoped by adding expected annualized results for the four frequencies analysed.
Total Annualized Stress Factor Losses	Total_Annualized_Stress_Factor_Losses	Total annualized mental stress and lost productivity costs expected for the sea level rise scenario. Developed by adding expected mental stress and lost productivity costs for the four frequencies analyzed.
Total Annualized Mental Stress	Total_Annualized_Mental_Stress	Total annualized mental stress costs expected for the sea level rise scenario. Developed by adding expected mental stress costs for the four frequencies analyzed.
Total Annualized Lost Productivity	Total_Annualized_Lost_Productivity	Total annualized lost productivity costs expected for the sea level rise scenario. Developed by adding expected lost productivity costs for the four frequencies analyzed.

Attribute	Field Name	Description
Total Annualized Losses	Total_Annualized_Losses	Total annualized losses for the sea level rise scenario. Developed by adding all expected consequences for the four frequencies analyzed.
Neighborhood	Neighborhood	Neighborhood the structure is located within, based on Martin's neighborhood boundaries.