Building data for climate change adaptation: filling data gaps and characterizing storm surge impacts in the Hudson River Valley and Long Island: Final Report

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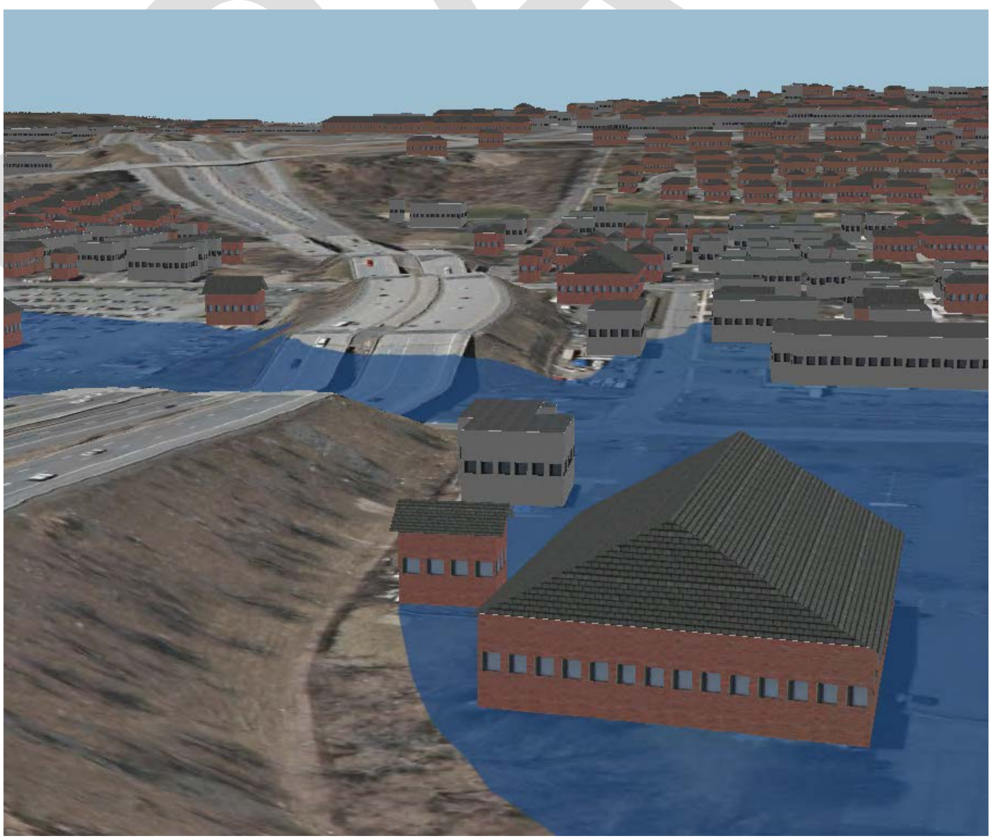

Contents

Introduction

Successfully adapting to climate change requires access to detailed data on the potential impacts from coastal and riverine flooding under different storm and sea level rise scenarios. Increasing storm severity and frequency have highlighted the need for more comprehensive and detailed data to increase preparedness for future impacts. CIESIN undertook a project funded by the New York State Energy Research and Development Authority (NYSERDA) to fill persistent data gaps and provide integrated critical infrastructure, building footprints, flood scenarios, and damage assessments to inform policy makers and empower citizens.

A new comprehensive collection of building footprints was developed for all of New York State (excluding New York City). The building footprint data set combines data collected from local governments and Microsoft, manually digitized from New York State Orthoimagery, and extracted from LiDAR data. Critical infrastructure data was collected from various national and local sources and attached (where applicable) to building footprints. Flood model data were assembled from a variety of sources to create a statewide model.

Information on economic valuations and modeled flooding were added to building footprints and used as inputs in a modified Hazards U.S. (HAZUS) flood assessment methodology to produce detailed estimates of possible flood impacts.

The flood scenarios, building footprints, and impact assessment statistics produced in this project are publicly available for use in regional and local planning and can be downloaded and incorporated into a user's own analysis. A web map application visually displays these data by county and municipality. The thousands of hours CIESIN spent collecting, creating, and validating the data and the support NYSERDA provided will allow others to reproduce the financial impact assessment and use the data for their communities' needs. The following document contains an exhaustive account of the data collection and integration, analysis methods, and a summary of the data and information available to the public.

Methodology

Building Footprints

I. Download

Online searches were conducted to find existing building footprint data. If building footprint data was not available online, it was requested from every county GIS office or planning department in New York (excluding New York City) and some municipal GIS offices.

II. Extract

The methodology to extract the building footprints from Light Detection and Ranging (LiDAR) data was compiled from various sources. The foundation of the methodology came from ESRI's 2017 workshop, "3D Mapping with Lidar Point Clouds Hands On Workshop Using ArcGIS® Pro 2.0"; first unveiled at the 2017 ESRI User Conference in San Diego, California. The CIESIN team heavily modified the tools and scripts provided by the ESRI tutorial to work specifically for the purposes of this project.

The LiDAR data was downloaded by project from the NYS Information Technology Services FTP. Due to their enormous size, the files were compressed to zLAS format, producing significantly smaller files that are optimized for Esri software. The zLAS files were combined into a LAS dataset (LASD).

Initial draft building outlines were produced by county from each LASD using the following processes:

1. A Digital Surface Model (DSM) and a Digital Terrain Model (DTM) raster were created for each zLAS file contained in the LASD.
    a. Statistics were calculated for each zLAS file to obtain the point spacing and classification codes.
    b. Using the cell sizes, classification codes, and tile extents, the DSM and DTM rasters were created by interpolating the elevation values of the LiDAR points in the LASD.
2. A mosaic dataset was created for each pair of corresponding DSM and DTM rasters.
3. The Esri MultiDirectional Hillshade template provided with the workshop materials was applied to the mosaic dataset to detect possible buildings over 2.5 meters in height. Cells representing possible buildings were reclassified to one and all others were reclassified to zero.
4. If a cell with a value of one did not have any direct neighbors with a value of one it was set to zero using the scipy convolve function.

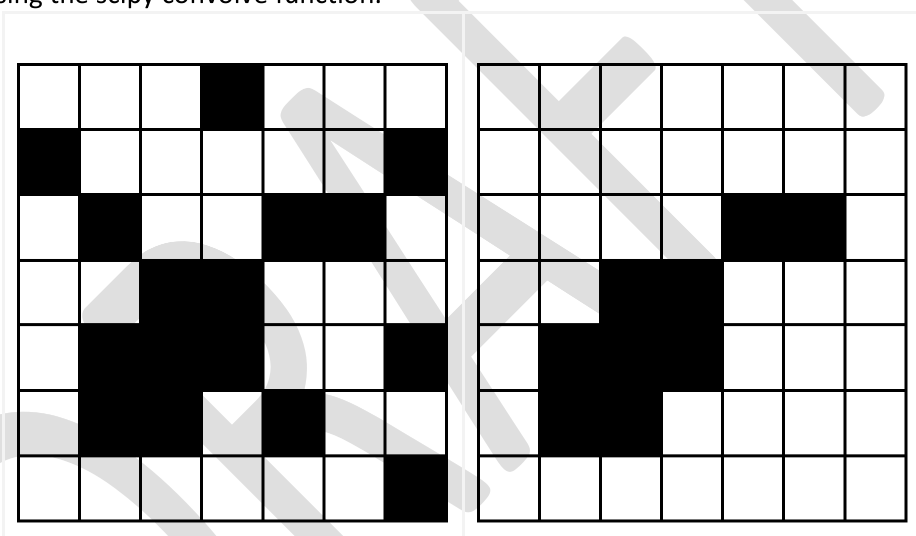

Fig 1: Mosaic dataset with the applied template before (left) and after (right) the scipy convolve function. Black cells represent possible buildings, with values of one, and white boxes have values of zero. Black cells with no direct neighbors were set to zero.

5. Finally, all cells with a value of one in the mosaic dataset were converted to a vector feature class representing the initial 'draft polygons'.

Draft polygons then went through additional processing to fill in gaps and reduce noise to create a final building footprint dataset:

1. Draft polygon feature classes were merged together at the county level. Polygons smaller than 1.5 square meters were discarded.
2. County-wide feature classes were dissolved to produce singlepart polygons.
3. Holes smaller than 10 square meters in polygons were filled in to create solid features.
4. Polygons more than 2 meters from an address point were discarded.
5. Esri's Regularize Building Footprints tool was used with the following parameters:
    a. Allow for right angles and diagonals

b. Tolerance = 1.5 meters
c. Densification = 1.5 meters
d. Precision = 0.15 meters
e. Diagonal Penalty = 2 meters

6. The feature classes were converted from multipart to singlepart polygons; features smaller than 10 square meters were discarded.
7. The Polbsy-Popper score, which measures compactness, was calculated for each polygon. Features with a score less than 0.4 were discarded.
8. The number of vertices of each polygon was calculated. Features with 16 or more vertices were discarded.

III. Digitize

If LiDAR data was not available for extraction and existing data was not available for download, building footprints were digitized manually using the most recent NYS Orthoimagery web service available.

A template ArcGIS map document for each municipality was used to define a standardized working session. The map document, coupled with strict standards and procedures, ensured consistent and reliable building footprints. Guidelines included the use of right angles, digitizing all buildings larger than a car, and capturing the roof type.

IV. Validate

The building footprints were validated to ensure the accuracy and quality of the final data product. If the footprints were separated by municipality, they were first merged to the county level and then all footprints were validated accordingly:

1. Points to Validate

For each municipality a separate data layer was created to collect "points to validate". During the digitizing workflow if the imagery resembled a building but it was difficult to distinguish a point feature was created to flag the area. Each point was checked by a person other than the one who created the point and buildings were added where appropriate.

2. Checked Topology

Topology rules were set up to catch overlapping features. If an overlap occurred, it was eliminated by merging it with one feature or merging both features together.

3. Checked Small Features

All polygons smaller than 100 square feet were individually checked. Polygons were deleted if they were smaller than a car or if they didn't correspond to a building in the NYS Orthoimagery web service imagery.

4. Checked Multipart Polygons

Multipart polygons were separated using the ArcGIS Multipart to Singlepart tool and individually examined. Polygons were either deleted, merged together, or left separated.

5. Used Housing Count in Census Blocks to Flag and Check Possible Errors

To determine possible building omissions and commissions building footprint datasets were checked against the Housing Count in the 2010 US Census. Census blocks were flagged as "errors of omission" if the census contained a housing count greater than zero but no building footprint features existed in the

block. These were checked against the NYS Orthoimagery web service. If the imagery contained a building then the missing polygon was digitized. “Errors of commission” were flagged if the census block contained a housing count of zero but there were building footprint polygons in the block. Each building was checked against the NYS Orthoimagery web service and features were deleted if no building was detected.
Note: “Errors of omission” were not checked for downloaded buildings.

V. Join additional attributes

After the building footprints were validated attributes were added to capture the geographic location and source information of each polygon. The buildings were spatially joined to administrative boundaries to attach the county and municipality that they fell into, and the source information was joined from the orthoimagery or LiDAR index files or manually filled in with information collected at the time of download.

Critical Infrastructure

I. Data acquisition

The critical infrastructure data was acquired from a variety of sources ranging from the Department of Homeland Security’s Homeland Infrastructure Foundation-Level Data (HIFLD) to the New York State GIS Program Office via the Clearinghouse. The raw data was either downloaded at the national or state level and with a temporal range from 2005 to 2017. Although most of the data was downloaded as vector point shapefiles, csv and vector polygon formats were also acquired. See Appendix 1 for a full list of critical infrastructure and sources.

II. Processing

Critical infrastructure layers were projected to NAD 1983 UTM Zone 18N and clipped to NYS administrative boundaries. The attribute tables were standardized to contain only ID, name, type (if applicable), and administrative boundary name fields.

III. Joining to buildings

The following process was used to join the critical infrastructure feature classes to the building footprints:

1. Joined point feature classes to the nearest tax parcel polygon with a corresponding property class.
2. If the selected parcel is greater than 500m from the point, join the point instead to the nearest parcel of any type.
3. Selected building footprints that lie in the joined tax parcel or polygon infrastructure feature classes and added an attribute listing the type(s) of critical infrastructure.
4. Any polygons that did not contain buildings were manually checked to ensure no buildings were overlooked in the digitizing process.

Flood Grids

The flood grids were produced using two different methods for inland and coastal waters. Inland flood grids were created using FEMA floodplain outlines and a simple model, while the Hudson River Estuary and Westchester coastline were produced using ‘dynamic’ water flood modeling. The below section details the processes to produce these two types of flood models. Both flood rasters are available for download in NAD 1983 UTM 18N.

I. Inland (FEMA)

The best available FEMA flood designations were stitched together using the Special Flood Hazard Areas (SFHA) and Q3 Flood Data. Although the SFHA data is more up-to-date, it is not geographically complete and was supplemented with the Q3 data.

The following steps were taken to transform the flood polygons into flood depth rasters:

1. Dissolved the polygons by floodplain classification to create 100- and 500-year flood outlines.
    a. 100-year: Open Water, 100-year Floodplain, 100-year Floodplain with coastal wave impacts
    b. 500-year: Open Water, 100-year Floodplain, 100-year Floodplain with coastal wave impacts, 500-year Floodplain
2. Converted the outlines to points.
3. Deleted points less than 300 meters from an adjacent point.
4. Extracted elevation values from the NYS Digital Elevation Model (DEM).
5. Interpolated using ESRI's Inverse Distance Weighting tool was used to create a raster surface of water elevation values with the same cell size as the DEM.
6. Subtracted the DEM from the interpolated surface to obtain a flood depth raster.
7. Clipped the resulting flood depth raster to the floodplain polygon outline.
8. Set negative or zero flood depth values to 0.1 feet.

II. Coastal (Stevens)

The Hudson River Estuary and Westchester coastline flood grid used in this project are based on "dynamic" water flow modeling that combines tides, storm surges, sea level rise, and tributary freshwater inputs to the Hudson. The flood zones for 5-year to 1000-year storm events were created using statistical analysis of data for a set of 881 storms – which includes all of the various types of storms that could strike the region. The dynamic flood modeling, developed by the Stevens Institute of Technology, includes both historical events and synthetic events. The latter are realistic tide/storm/rain combinations that have not occurred in the limited historical record, which improved the estimation of low-probability flood events such as the 100-year (1% annual chance) or 1000-year (0.1% annual chance) flood.

The flood models were provided as points along transects and went through the following processes to produce coastal flood rasters:

1. ESRI's Radial Basis Functions tool was used to create an interpolated raster surface of water elevation values with the same cell size as the DEM.
2. The DEM was subtracted from the interpolated surface to create the flood depth raster.
3. Determine areas of possible disconnected flooding
    a. The flood depth raster values were converted to binary codes with a zero representing a flood depth of zero, and a one representing a flood depth greater than zero
    b. The binary raster was converted to a polygon feature class
    c. Values not equal to one and that did intersect the Hudson River extent were eliminated. The remaining polygons represent areas of possible disconnected flood. (i.e. the polygons have a flood depth value, but do not intersect the Hudson River)
    d. Areas of disconnected flooding were added to the flood depth rasters and were set to -9999.

Impact Assessment

The FEMA Hazus-MH flood loss estimation methodology was modified for this project and scripted to run outside of the Hazus application. Data and methods were extracted from the user and technical manuals.

The first and most complicated steps were adding all of the attributes required for the depth-damage functions used in the Hazus process:

1. Tax parcel data was separated by county and cleaned to resolve duplicate or overlapping geometry.
2. 300 tax parcel property classes were matched to the 28 Hazus occupancy classes using their Standard Industrial Classification (SIC) codes.
    a. In cases with no clear match, general occupancy classes were created such as RESX or X (residential or mix, respectively).
3. The tax parcels were joined to the building footprints.
    a. Footprints containing multiple parcels were given the sum value of those parcels
    b. If more than one building was present in a parcel, they were given an area-weighted proportion of the parcel value
    c. If a building did not fall into a parcel or the parcel did not have any information, it was joined to Hazus block-level data
4. Attributes from provided Hazus block-level data were joined to the building footprints.
5. Flood zone (A, V, or Riverine) was determined by location relative to the SFHA vector data
6. Tables from the Hazus user manuals were used to determine the most likely First Floor Elevation for every building based on the block type, FIRM entry date, year built, flood zone, and occupancy class.
7. Table 14.6 (Default Hazus Contents Value Percent of Structure Value) was edited to include the general occupancy classes added in step 2, and applied to the building footprints.

Table 1: Data source of building attributes

Attribute	Source
Occupancy Class	Tax parcels
Year Built	
Building Value	
FIRM Entry Date	Hazus block level data
Block type	
Flood zone	SFHA designation
First Floor Elevation	Hazus manual tables
Contents Value	

Next the analysis was done:

1. The Hazus depth-damage functions for both buildings and contents were modified to eliminate attributes that were not available (number of stories, presence of a basement) and to add average functions for the additional general occupancy classes.
2. The depth of flooding was extracted from the flood grids using the zonal statistics tool.
3. The depth-damage functions were applied to each building to get an estimate of impact due to 100- and 500-year floods.
4. The damage percentages were converted to the FEMA damage classifications (None, Slight, Moderate, and Substantial) at the building level.

5. Damages were aggregated to the block group, municipality, and county levels.

Adaptation Options
Adaptation options specific to each building occupancy class were determined and attached to building footprints. See Appendix 3 for the full list of adaptation options.

Data available for download

Building Footprints. Polygons of building footprints with damage categories and use type attributes.

Flood Grids. Flood depths as GeoTiff files.

Impact Estimate. Impact estimates (dollars) for census units (block groups), municipalities, and counties.

The Web Map Application

The web map application allows users to view the building footprints and query the damage category for each building in a flood zone. The search bar allows users to lookup street addresses, towns or counties to zoom to a particular location in the State; destinations, such as a stadium name or popular tourist destination, are also supported. The county, municipal, and block group layers can be enabled and queried to view a summary of damages for those units (if applicable). Critical infrastructure is also visible in the viewer and buildings that are both critical infrastructure and in the flood zone can have the damage category attributes displayed.

Appendices

Appendix 1: Data Sources

A variety of data sets were used to produce not only the building footprint data, but the critical infrastructure and flood scenarios as well. Below is a summary of the organizations and government agencies that data was collected from.

Building Footprints

Source	Coverage
<Broome County GIS and Mapping Services (GIS Portal)>	Broome
Cortland County Planning Department	Cortland
Dutchess County Office of Central and Information Services	Dutchess
Town of Tonawanda Technical Support Department	Tonawanda (town), Erie
City of Rochester Department of Information Technology	Rochester, Monroe
Nassau County Office of Information Technology	Nassau
Oneida County Department of Planning	Oneida
Ontario County GIS Data Resource Center	Ontario
Orange County GIS Division	Orange

Oswego County Real Property Tax Service	Oswego
Rockland County GIS Division	Rockland
Saratoga County Planning Department	Saratoga
Schenectady County Planning Department	Schenectady
Steuben County Planning Department	Steuben
Suffolk County Department of Information Technology	Suffolk
Sullivan County Real Property Tax Services	Sullivan
Tompkins County ITS GIS Division	Tompkins
Ulster County Information Services	Ulster
Westchester County Geographic Information Systems	Westchester

Microsoft
USBuildingFootprints. June 2018. Microsoft. https://github.com/Microsoft/USBuildingFootprints. Accessed 06/29/2018.

LIDAR
< insert citation >

Critical Infrastructure

Name	Source	Coverage	Date of Data
State Emergency Operations Centers	Department of Homeland Security's HIFLD	National	2015
Local Emergency Operations Centers (EOC)	Department of Homeland Security's HIFLD	National	2009
Emergency Medical Service (EMS) Stations	Department of Homeland Security's HIFLD	National	2010
Fire Stations	Department of Homeland Security's HIFLD	National	2010
Health Facilities	NYS Department of Health	State	2017
Nursing Homes	Department of Homeland Security's HIFLD	National	2017
Places of Worship	Department of Homeland Security's HIFLD	National	2016
Police Departments	Department of Homeland Security's HIFLD	National	2017
Power Plants	U.S Energy Information Administration	National	2017
Prisons	Department of Homeland Security's HIFLD	National	2017
Public Libraries	Amy Heebner, Division of Library Development, New York State Library	State	2017
Public Schools (K-12)	NYS Department of Education and NYS GIS Program Office	State	2017
Private Schools	Department of Homeland Security's HIFLD	National	2015

Colleges and Universities	Department of Homeland Security's HIFLD	National	2015
Wastewater Facilities	New York State Department of Environmental Conservation	State	2011

Flood Grids

Orton, P., MacManus, K., Fico, A., Mills, J., F. Conticello, F. Cioffi, T. Hall, N. Georgas, U. Lall, A. Blumberg. 2018. Hudson River and Western Long Island Sound Flood Elevations from Tides, Storm Surge and Rainfall. New York.

Appendix 2: Building Footprint attribute table

Field Name	Description
BuildingID	The unique building identifier. The first three digits represent the county fips code and the digits to the right of the underscore are sequential unique integers.(i.e. BuildingID '001_1' represents Albany county building number 1)
CountyName	The name of the county
MuniName	The name of the municipality
Source	The data source of the feature: 1) NYS Digital Orthoimagery 2) NYS ITS LiDAR: <Name of LiDAR Project> 3) Organization that provided the building footprints or Microsoft Building Footprints Release <V1.0 or V1.1>
SourceID	The specific source of each feature 1) The orthoimagery tile ID 2) The LiDAR tile ID 3) Any ID included with a downloaded data source
SourceDate	The date of the data used to create the feature 1) The date of the orthoimagery 2) The date of the LiDAR 3) The date the downloaded data was created
RoofType	The roof type of each feature 1) Peaked 2) Flat 3) Unknown 4) NULL
InfrType	The type(s) of critical infrastructure
OccClass	FEMA Hazus-MH occupancy class
FFE	First Floor Elevation (feet)
LossCat100	Category of loss from FEMA 100-year flood (None, Slight, Moderate, Substantial)
LossCat500	Category of loss from FEMA 500-year flood (None, Slight, Moderate, Substantial)
Adaptation	Flood adaptation option(s) for building of specific occupancy class
AdptSource	Sources of adaptation options

Appendix 3: Adaptation Options

Occupancy Class	Adaptation
AGR1	(1) Integrate grass buffers, hedgerows, bunds, riparian buffer strips, temporary ponds, and ditching into agricultural land (2) Plant seasonal cover crops (3) Extensification and restricted grazing season (4) Maintain and/or realign channels
COM1	(1) Dry floodproof mechanical systems below BFE or elevate critical systems above BFE (2) Wet floodproof space below BFE and fill basement to lowest adjacent grade (3) Make a plan for protecting or moving inventory
COM2	(1) Dry floodproof mechanical systems below BFE or elevate critical systems above BFE (2) Wet floodproof space below BFE (3) Plan for protecting or moving inventory (4) Run elevators to upper landing, turn off disconnects, shut and cover all openings
COM3	(1) Elevate structures such that the lowest floor is above BFE (2) Dry floodproof mechanical systems below BFE, or elevate systems above BFE
COM4	(1) Offices and work spaces should be kept out of floodplain as much as possible (2) Dry floodproof critical systems below BFE, or elevate systems above BFE (3) Make a plan for protecting or moving inventory
COM5	(1) Offices should be kept out of floodplain as much as possible (2) Develop a plan to keep employees and communication channels safe
COM6	(1) Floodproof, ensure there is backup power, and keep generators as safe as possible from floods (for example, on the roof) (2) Develop a flood emergency operations plan, as well as continual maintenance (3) Maintain sensitive functions above BFE
COM7	(1) Floodproof, ensure there is backup power, and keep generators as safe as possible from floods (for example, on the roof) (2) Develop a flood emergency operations plan, as well as continual maintenance (3) Maintain sensitive functions above BFE
COM8	(1) Store food and perishables in waterproof containers above BFE (2) Build a mezzanine for storage or termporary relocation of valuable equipment
COM9	(1) Store food and perishables in waterproof containers above BFE (2) Install the HVAC system on the roof to reduce exposure to floodwaters
COM10	(1) Reduce excessive paved surface, use pervious surfaces where possible
COMX	(1) Elevate the site, utilities and mechanical equipment above the BFE (2) Wet or dry floodproof, reinforcing walls against floodwater (3) Install drainage collection, sump pumps, and backflow prevention measures for sewage systems
EDU1	(1) Elevate the site and all utilities above the BFE; anchor and protect all plumbing, water supply, gas lines, or electric cables below the BFE; prewire portable generator connections and install surge protection and uninterruptible power supplies
EDU2	(1) Elevate the site and all utilities above the BFE; anchor and protect all plumbing, water supply, gas lines, or electric cables below the BFE; prewire portable generator connections and install surge protection and uninterruptible power supplies
EDUX	(1) Elevate the site and all utilities above the BFE; anchor and protect all plumbing, water supply, gas lines, or electric cables below the BFE; prewire portable generator connections and install surge protection and uninterruptible power supplies
GOV1	(1) Establish local emergency response systems that can coordinate with municipality and county (2) Ensure that emergency response facilities are floodproofed or out of floodplain, if possible (3) Encourage development in less vulnerable areas
GOV2	(1) Establish local emergency response systems that can coordinate with municipality and county (2) Ensure that emergency response facilities are floodproofed or out of floodplain, if possible (3) Encourage development in less vulnerable areas
GOVX	(1) Establish local emergency response systems that can coordinate with municipality and county (2) Ensure that emergency response facilities are floodproofed or out of floodplain, if possible (3) Encourage development in less vulnerable areas

IND1	(1) Elevate lowest floor above BFE or dry floodproof the entire building (2) Install green infrastructure where possible (3) Store electrical and mechanical equipment above BFE
IND2	(1) Elevate lowest floor above BFE or dry floodproof the entire building (2) Install elevated mezzanines to relocate equipment and inventory (3) Store electrical and mechanical equipment above BFE
IND3	(1) Floodproof critical storage spaces and wet floodproof offices (2) Store food and perishables in waterproof containers above BFE (3) Prepare a plan to protect brewing equipment and relocate vehicles (4) Bolt tanks to platforms and elevate above BFE
IND4	(1) Equipment should be located away from floodwaters, for example on the roof, on the landward side of a building, behind a structural element (2) Install elevated mezzanines to relocate equipment (3) Store electrical and mechanical equipment above BFE
IND5	(1) Equipment should be located away from floodwaters, for example on the roof, on the landward side of a building, behind a structural element (2) Install elevated mezzanines to relocate equipment (3) Store electrical and mechanical equipment above BFE
IND6	(1) Elevate equipment above BFE (2) Use anchors and tie-down straps to keep shelves and materials in place
INDX	(1) Equipment should be located away from floodwaters, for example on the roof, on the landward side of a building, behind a structural element (2) Install elevated mezzanines to relocate equipment (3) Store electrical and mechanical equipment above BFE
REL1	(1) Obtain flood insurance (2) Elevate furnace, water heater, and electric panel (3) Incorporate flood openings below BFE, and ensure waterproof building materials (4) Develop a plan to keep community members safe
RES1	(1) Obtain flood insurance (2) Elevate furnace, water heater, and electric panel (3) Install "check valves" (4) Incorporate flood openings below BFE, and ensure waterproof building materials
RES2	(1) Keep out of floodplain, or elevate and anchor home (2) Keep utilities, water heaters, and mechanical devices above BFE
RES3	(1) Obtain flood insurance (2) Elevate furnace, water heater, and electric panel (3) Install "check valves" (4) Incorporate flood openings below BFE, and ensure waterproof building materials
RES4	(1) Store food and perishables in waterproof containers above BFE
RES5	(1) Obtain flood insurance (2) Elevate furnace, water heater, and electric panel (3) Install "check valves" (4) Incorporate flood openings below BFE, and ensure waterproof building materials
RES6	(1) Keep an alternate power source (2) Ensure that generators are as safe as possible from floods by keeping them on the roof
RESX	(1) Obtain flood insurance (2) Elevate furnace, water heater, and electric panel (3) Install "check valves" (4) Incorporate flood openings below BFE, and ensure waterproof building materials
X	(1) Elevate lowest floor above BFE (2) Elevate mechanical equipment (3) Wet floodproof with water resistant materials (4) Dry floodproof to seal with removable barriers (5) Limit use below BFE to allow movement of water