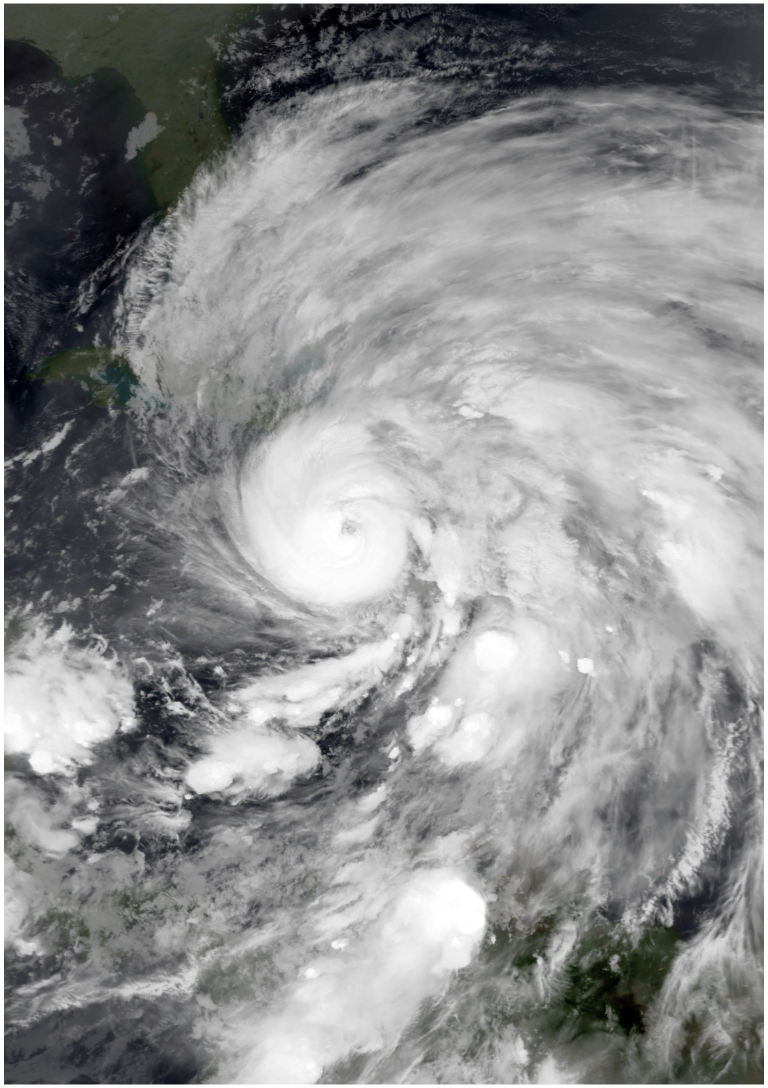


Resiliency and Concrete

ACI – Charleston

Aditya Bhagath P.E.
Senior Project Director

February 12, 2020

Thornton Tomasetti

Agenda

- Resilience
- Business Case for Resilience
- Resilience Approach
- Climate Projections and Guidelines
- Resilient Design Practices
- Resilience Design with Concrete and Challenges

Resilience
What, Why & How?

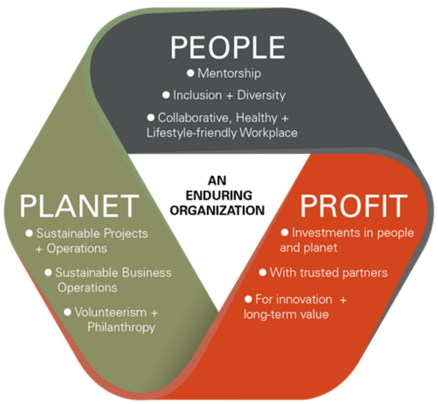
Resilience...

... to prepare, endure, adapt and thrive in a disruptive and changing world.

Sustainability aims to slow the impact of energy and resource consumption and put the world back in to balance

+

Resilience looks for ways to manage and thrive in an imbalanced world.



Why Resilience?

- Climate change resulting in:
  - Rising sea levels and warming oceans
  - Rising groundwater
  - Severe droughts
  - Heavy precipitation events
  - Excessive heat
  - Wildfires

- Increases in intensity, duration, frequency and geographic extent of weather and climate extremes

- Increasing global natural disaster losses– nearly $133 billion in 2019 (~40% of these losses were insured)

- Growing population concentration in vulnerable areas

Cascading Impacts


The New York Times

Amid Heat Wave in New York, 50,000 Lose Electricity

Early Monday, Con Edison said 30,000 had their power restored and the remaining would have power restored by the afternoon.

Milo Maimone, 8, and his dad, Tony, rest after working out at the McCarren Park track in Brooklyn on Sunday Gabriella Angotti-Jones for The New York Times

Business Case for Resilience

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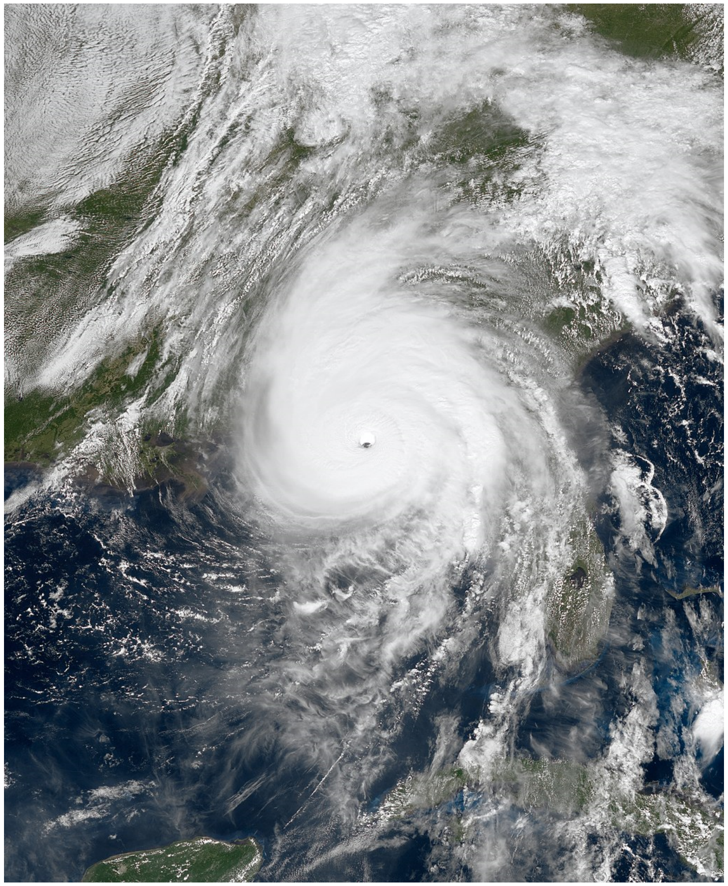
Benefits of Resilient Design



Among the Ruins of Mexico Beach Stands One House, Built 'for the Big One'

The elevated house that the owners call the Sand Palace, on 36th Street in Mexico Beach, Fla., came through Hurricane Michael almost unscathed. Johnny Milano for The New York Times

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Benefits of Resilient Design

Equation 1. Benefit-Cost Ratio Formula

$$BCR = \frac{BENEFITS}{COSTS}$$

Where: BCR = Benefit-Cost Ratio

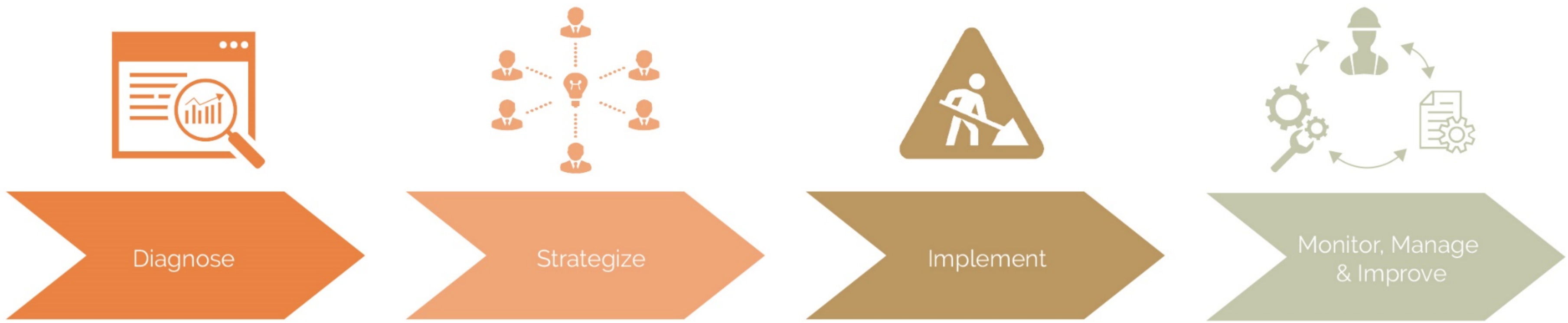
BENEFITS = Total project benefits

COSTS = Total project costs

- Direct Benefits
  - Include reduced or avoided physical damages to facilities
  - Reduced or avoided displacements of residents
  - Reduced life cycle or O&M costs
- Indirect Benefits
  - Include reduced or avoided service losses for non-residential buildings, public facilities and/or infrastructure (utilities, roads and bridges)
- Other Benefits like social benefits for residents such as
  - Avoided stress and anxiety
  - Avoided lost productivity
  - Environmental/ecosystem service benefits
  - Avoided need for emergency services

Resilience
Approach

Resilience Approach



Assessment of site specific vulnerabilities to shocks and stresses considering trends and opportunities

Develop holistic integrated resilience strategy

Design and Build physical and operational risk reduction measures

Dynamic nature of clients' challenges requires constant review, learning and innovation

BOD/Concept Design

SD-DD-CD-CA

Project Close Out - Ongoing

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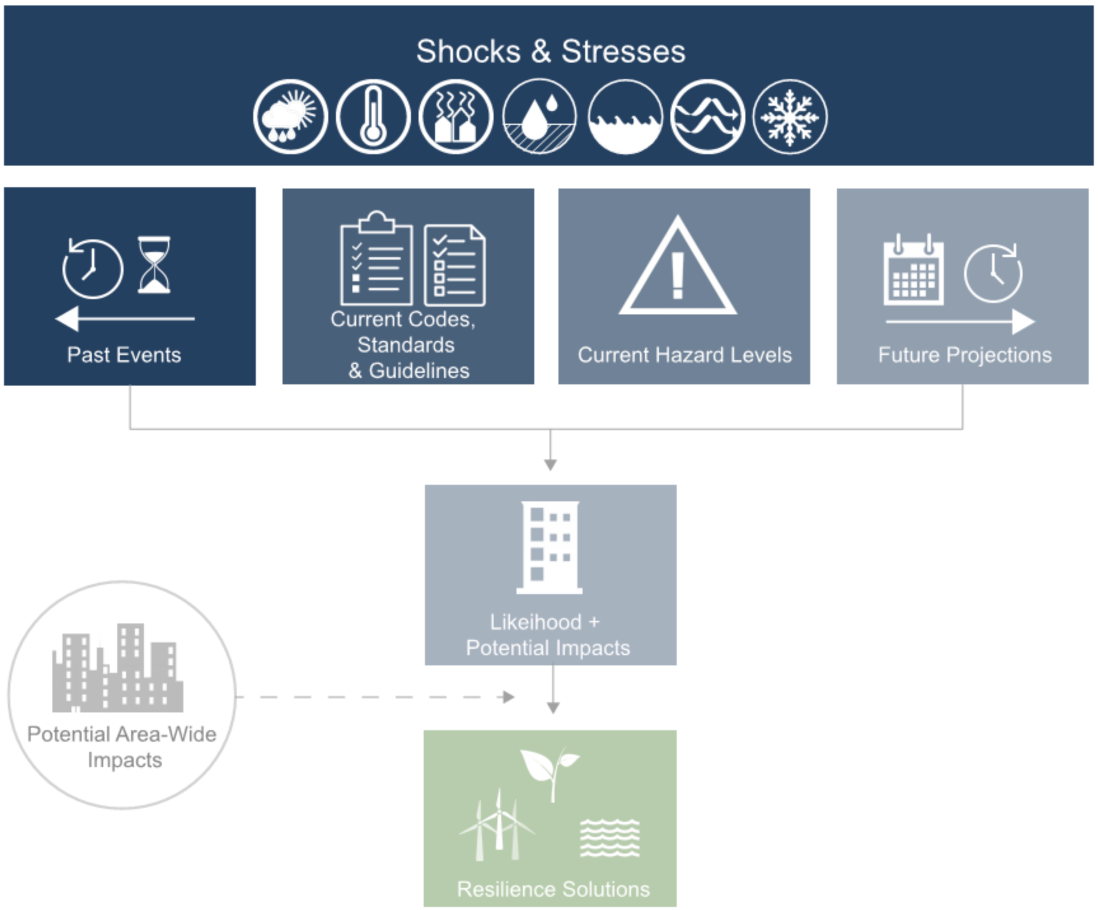
Site-Specific Risk & Resilience Assessment Overview

Process Overview



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Risk & Resilience Assessment Overview

Shocks and Stresses

Natural

- Flooding
- Storm surge
- Hurricanes and tropical storms
- High winds
- Tornados
- Rainfall
- Earthquake
- Snow and ice
- Severe thunderstorms
- Nor'easters
- Extreme heat
- Heat waves
- Drought
- Rodents, insects, and other pests
- Wildfires
- Landslides

Man-Made

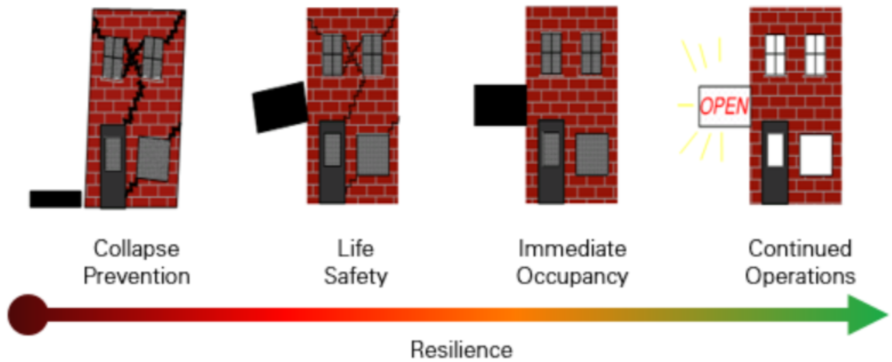
- Climate change
  - Sea level rise
  - Rising groundwater
  - Increasing precipitation
  - Increasing heat
- Fire
- Air pollution
- Mechanical failure
- Grid failure
- Aging infrastructure
- Hazardous material spill
- Contagious disease outbreak
- Noise pollution
- Sonic attack
- Conflict
- Market failures
- Electromagnetic pulse (EMP) attack
- Blasts and explosions
- Active shooter situations
- Cyber attack
- Vehicle ramming
- Forced entry
- Crime and violence
- Security system failure
- Theft and burglary
- Chemical or biological attack
- Nuclear disaster
- Technological changes
- Light pollution

Impacts

People	The extent of personal discomfort, harm, injury, or loss of life.
Physical Assets	Loss or damage to structural and architectural building components, MEP and IT equipment, utilities, landscaping or contents.
Operations	Disruption to building operations and functionality, occupancy, egress/ingress, critical systems, or lab activities.
Revenue	Loss of revenue due to business interruption, specifically in relation to occupants/tenants.
Reputation	Negative media attention or impact on industry reputation in the aftermath of an impactful shock or stress.

Performance Objectives

Physical Assets and Operations



Building Performance Levels

Collapse Prevention	Building sustains damage and retains no margin against collapse post-event.
Life Safety	Building is damaged but retains a margin of safety.
Immediate Occupancy	Building structure retains its strength, building is safe and functional to re-occupy.
Continued Operations	Very light damage, building is operational during and immediately after the event.

Operational Performance Levels

L1. Maintain life safety operations

L2. Maintain life safety and other critical operations

L3. Maintain operations of all critical operations and work spaces

L4. Maintain the entire building operations, including lobbies

Climate

Projections and Guidelines

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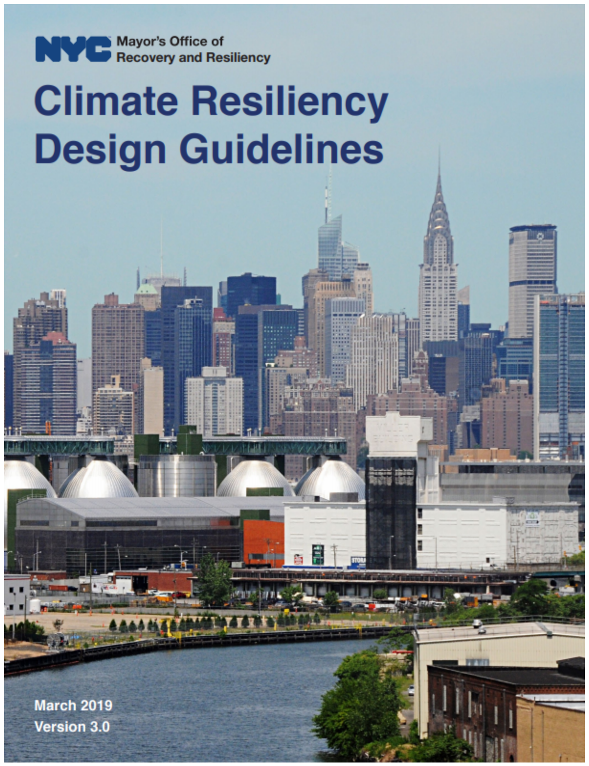
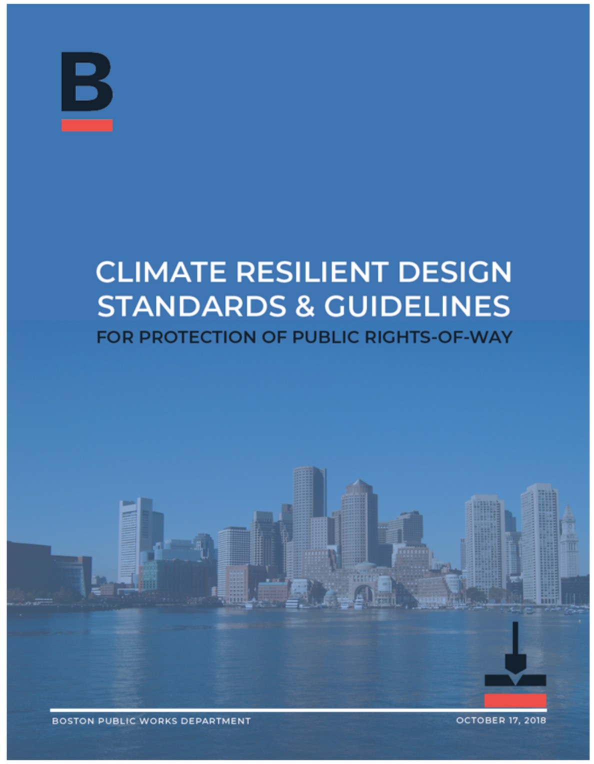
Climate Projections

Design Guidelines





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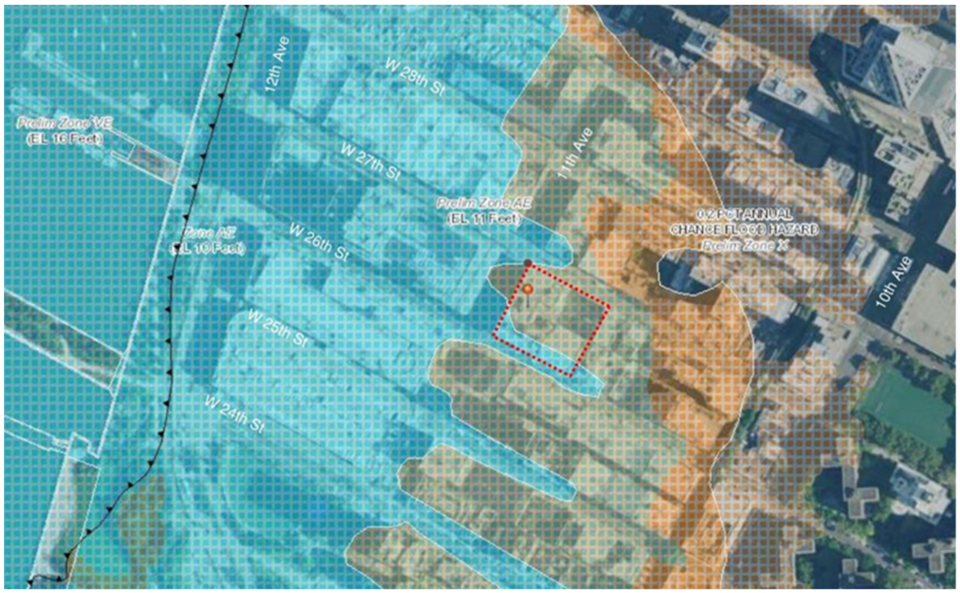
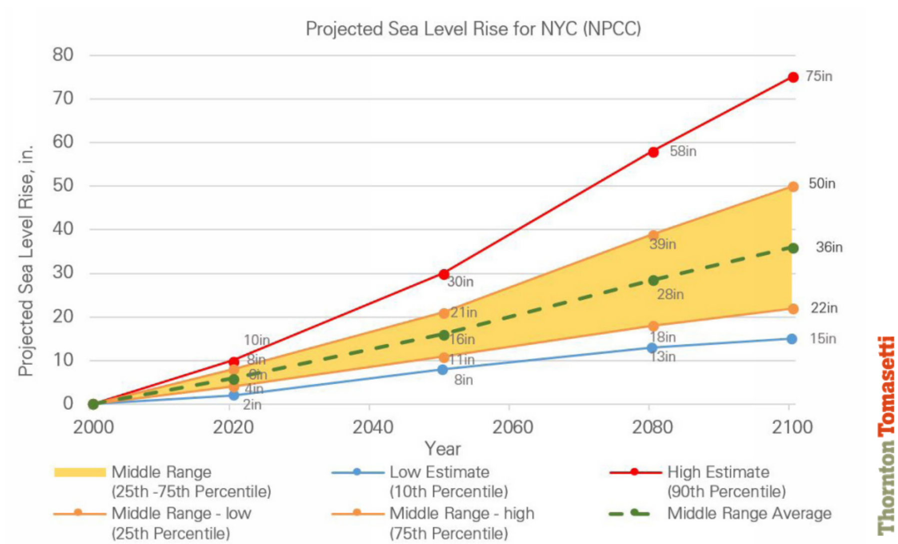
Climate Projections

Flooding and Storm Surge

- Sandy resulted in flooding at the site in October 2012
- Building Code for the site: Category II Building DFE = BFE +1’ = 11’ NAVD88 + 1’ = 12’ NAVD88
- Sea Level Rise: Middle Range 2080 Scenario DFE = 14.33ft NAVD88





Climate Projections

Extreme Heat

Table 2 – Current and projected extreme heat events and design criteria[27]

	Extreme heat events			*Design criteria*	
End of useful life	**# of heat waves per year**	**# days at or above 90°F**	**Annual average temperature**	**1% Dry Bulb temperature**	**Cooling Degree Days** *(base = 65°F)*
Current (1971-2000)	**2**	**18**	**54°F**	**91°F**	**1,149**
2020s (through to 2039)	**4**	**33**	**57.2°F**	**--**	**--**
2050s (2040-2069)	**7**	**57**	**60.6°F**	**98°F**	**2,149**
2080s (2070-2099)	**9**	**87**	**64.3°F**	**--**	**--**

Note: Due to HVAC system typical useful life of around 25 years, only design criteria projections for the 2050s are shown. Projections for the 2020s are not shown because it is anticipated that enough of a safety margin is employed already in current systems to withstand the temperature rise expected through the 2020s. The NPCC is developing projections of 1% Wet Bulb temperatures, which are expected to increase. This design criteria will be added in a later version of the Guidelines.

Climate Projections

Increasing Heat

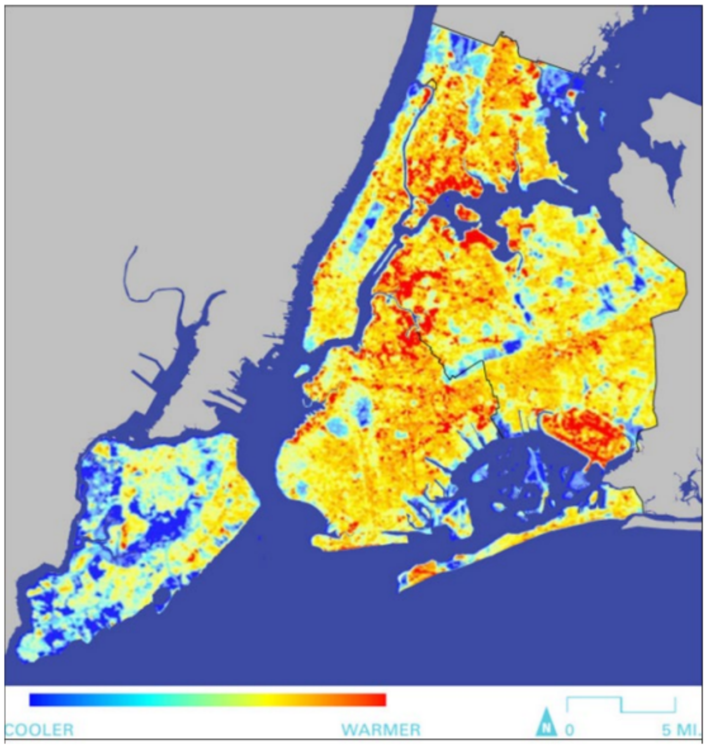


Figure 3 - Thermal imagery of New York City, based on LANDSAT Thermal Data from 8/18/2009[14]

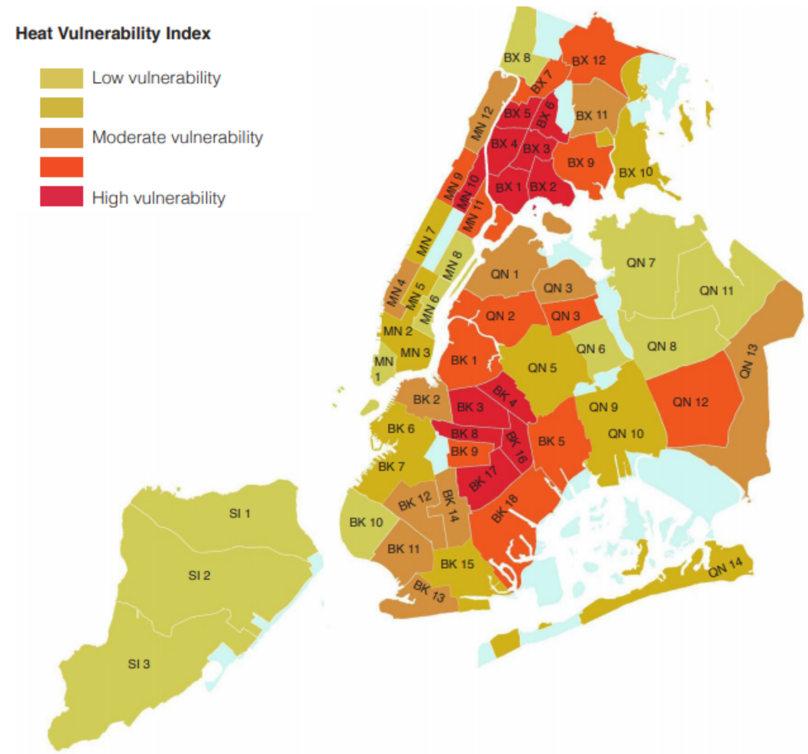


Figure 4 - Heat Vulnerability Index (HVI) for New York City Community Districts (Source: NYC DOHMH 2015). This analysis identifies physical, social, and economic factors associated with increased risk of heat-related morbidity and mortality.[17]

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Climate Projections

Increasing Precipitation

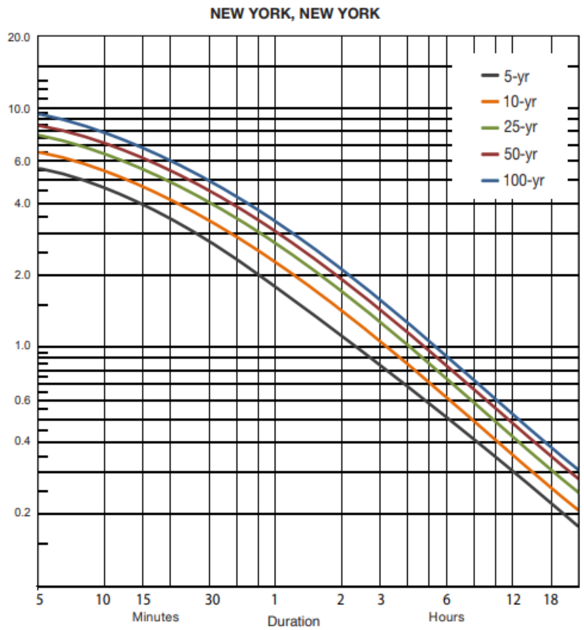


Figure 5 - Current Intensity-Duration-Frequency Precipitation Curve for NYC, adapted from U.S. Department of Commerce Weather Bureau Technical Paper 25.

Table 8 – Projected mean annual changes[92]

a. Temperature Baseline (1971-2000) 54°F	Low estimate (10th percentile)	Middle range (25th to 75th percentile)	High estimate (90th percentile)
2020s	+ 1.5°F	+2.0-2.9°F	+3.2°F
2050s	+3.1°F	+4.1-5.7°F	+6.6°F
2080s	+3.8°F	+5.3-8.8°F	+10.3°F
2100	+4.2°F	+5.8-10.4°F	+12.1F
b. Precipitation Baseline (1971-2000) 50.1 in	**Low estimate (10th percentile)**	**Middle range (25th to 75th percentile)**	**High estimate (90th percentile)**
2020s	-1 percent	+1-8%	+10%
2050s	+1 percent	+4-11%	+13%
2080s	+2 percent	+5-13%	+19%
2100	-6 percent	-1% to +19%	+25%

Note: Based on 35 global climate models (GCMs) and two RCPs. Baseline data cover the 1971–2000 base period and are from the NOAA National Climatic Data Center (NCDC). Shown are the low estimate (10th percentile), middle range (25th percentile to 75th percentile), and high estimate (90th percentile). These estimates are based on a ranking (from most to least) of the 70 (35 GCMs times 2 RCPs) projections. The 90th percentile is defined as the value that 90 percent of the outcomes (or 63 of the 70 values) are the same or lower than. Like all projections, the NPCC climate change projections have uncertainty embedded within them. Sources of uncertainty include data and modeling constraints, the random nature of some parts of the climate system and limited understanding of some physical processes. The NPCC characterizes levels of uncertainty using state-of-the-art climate models, multiple scenarios of future greenhouse gas concentrations and recent peer-reviewed literature. Even so, the projections are not true probabilities and the potential for error should be acknowledged.

Resilient
Design Practices

Dry vs. Wet Floodproofing

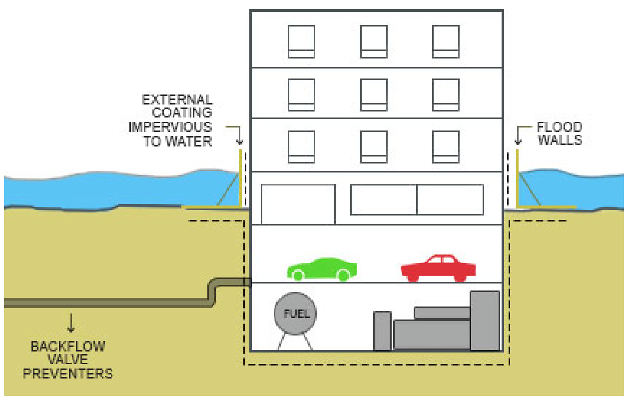
What is the difference?

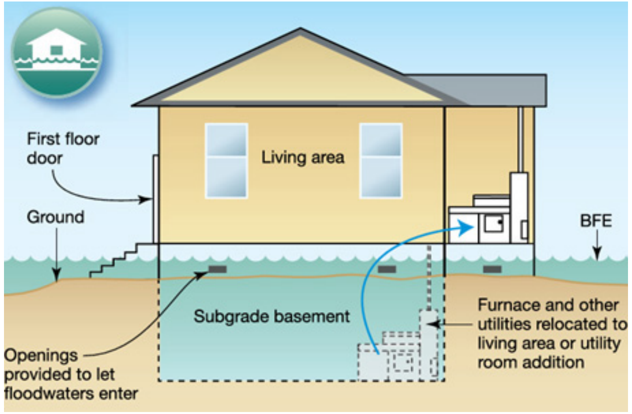
Dry Floodproofing

Dry floodproofing consists of a watertight structure where no floodwater enters a structure. This is made possible by sealing the walls with waterproof coatings, impermeable membranes, or a supplemental layer of masonry or concrete.

Wet Floodproofing

Wet floodproofing allows flood waters to enter the structure quickly in order for the interior flood water level matches the exterior flood water level. This equilibrium causes hydrostatic pressures, including buoyancy to have less of an effect on the property.





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Flood Loading

Types Of Flood Loading

- Hydrostatic (Lateral and Uplift)
- Hydrodynamic
- Wave loads (Breaking and Non-Breaking)
- Impact loads due to floating debris

Hydrostatic Pressure on dry flood proofed buildings.

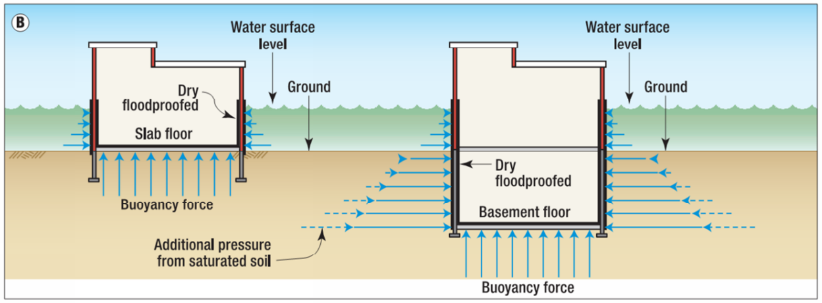
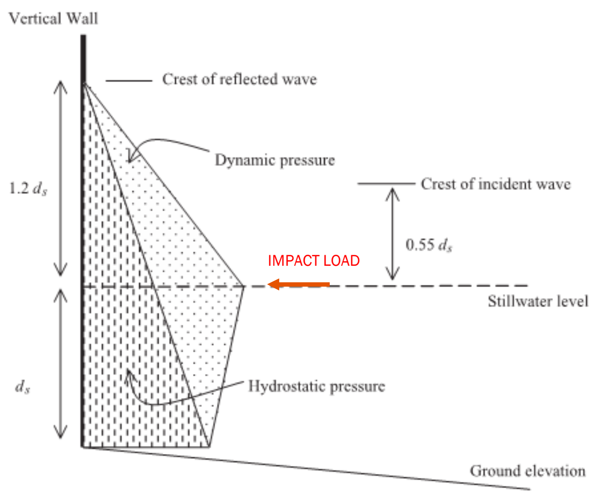


Image from Floodproofing Non-Residential Buildings FEMA P-936 / July 2013



Flood Loading

Debris Impact Loading

ASCE 7-16 – Chapter 5

5.4.5 Impact Loads

Impact loads are those that result from debris, ice, and any object transported by floodwaters striking against buildings and structures, or parts thereof. Impact loads shall be determined using a rational approach as concentrated loads acting horizontally at the most critical location at or below the DFE.

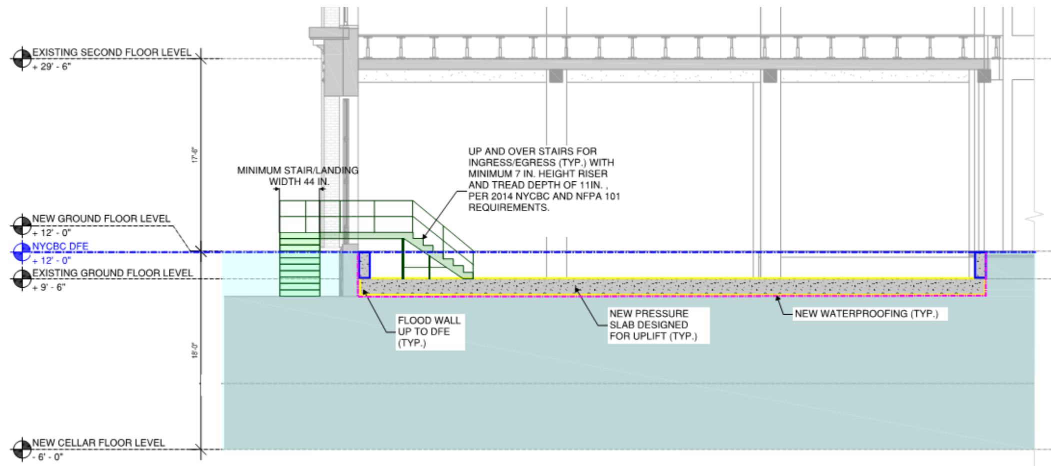
NY TIMES ARTICLE

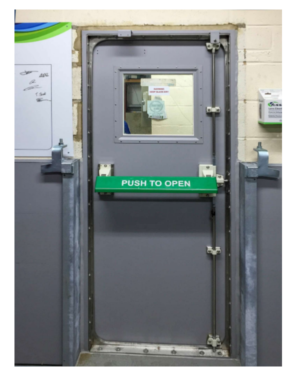
To make things worse, an oil tanker unmoored by the powerful typhoon's 130 mile-per-hour winds struck and damaged the only bridge to the mainland. With nowhere to go, 8,000 people huddled in darkened terminals overnight as waves lapped at the buildings' walls, before emergency ferries and buses found a way to navigate the mangled bridge and shuttled passengers to safety.

Dry Floodproofing Design

Typical Measures

- Pressure slab
- Flood walls
- Flood barriers, doors, gates
- LinkSeals
- Backflow valves and hardened pipes
- Egress/ingress
- Flood Emergency Action Plan





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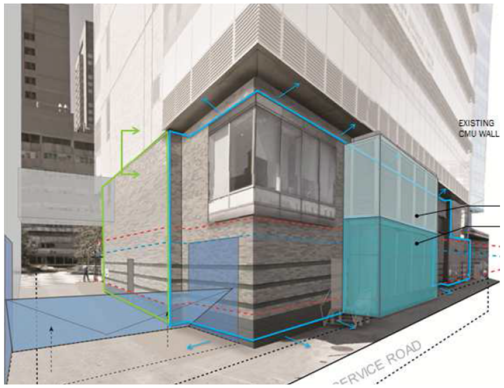
Flood Resilience Strategy

Combination of Flood Mitigation Solutions

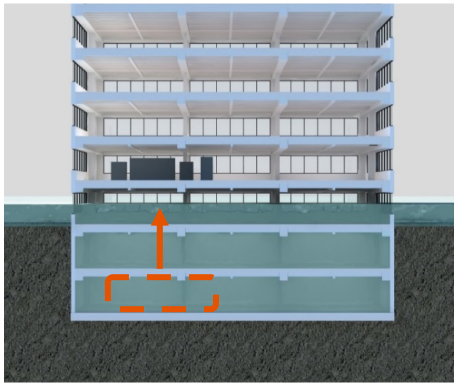


Exterior – Perimeter Protection

Wall reinforcement
Flood barriers and doors
Slab reinforcement
Fill in areaways
Enclose exterior penetrations
Backflow prevention

Water Management & Compartmentalization

Interior flood doors/barriers
Building and critical infrastructure compartmentalization
Pumps/sump pumps



Elevation & Power Generation

MEP systems elevation
Program & service equipment elevation
Emergency Power

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Resilient Design
with Concrete

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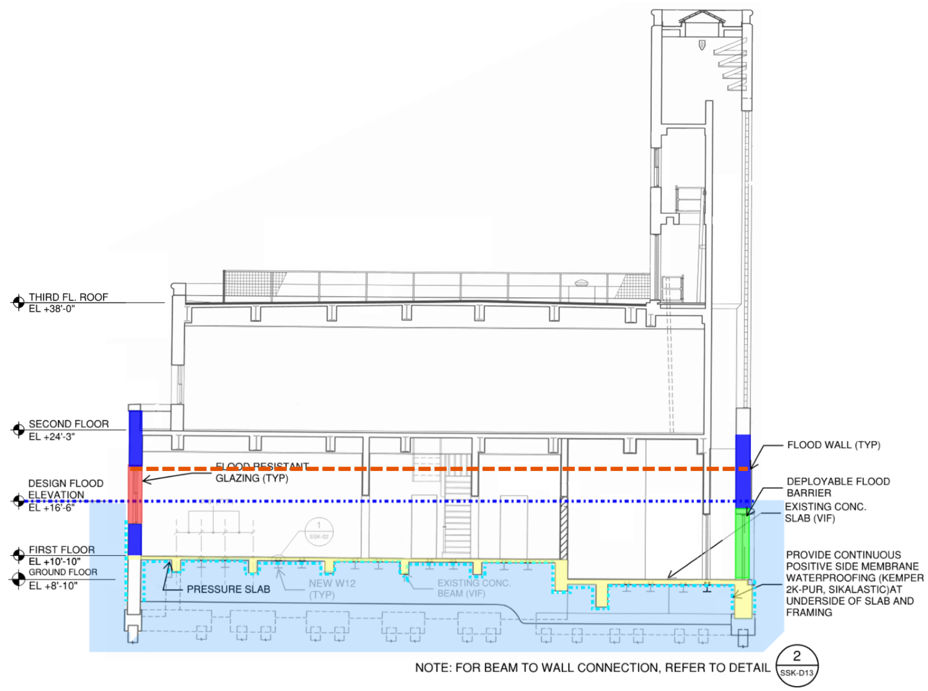
Resilient Design with Concrete

Resilient Design Practices

- Climate adaptive design with concrete for minimal upfront costs and potential ease of incremental upgrades
  - Pressure slabs
  - Flood walls
- Floating debris impact load resistance capacity
- Retrofit of existing concrete structures
- CO_2 mineralization



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Resilient Design with Concrete

Challenges

- Need for aesthetic exposed concrete that remains watertight to storm surge driven inundation and rainfall
- Currently using waterproofing membrane and façade elements in order to cover the exposed membrane leading to added time and costs
- Guidelines from multiple ACI resources (ACI 350, ACI 357.3 , ACI 301) that can be combined to inform resilient design practices

Resilient Design with Concrete

Challenges

- Guidelines from the concrete industry that provide a direct response to the advantages that concrete construction offers to future risks/projections laid out in various climate change guidelines.
    - Heatwaves
    - Extreme Heat
    - Increased Precipitation
    - Flooding + Sea Level Rise

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