# **Planning for Resilient Infrastructure to Adapt to Climate Change** – a coastal island Massachusetts community case study

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# **Presentation** overview

- Introduction
  - Climate change
- One design approach (example of a small community)
  - FEMA flood maps
  - Sea level rise
  - Freeboard
- Summary
- Questions

# **Climate** change

- Change in frequency and intensity of storms
- Global sea level rise
- Financial damages
  - National Weather Service and Insurance Information Institute: 9 out of the top 10 costliest natural disasters in the United States were climate related (hurricanes, floods, droughts) between 1980 and 2010
    - 7 were from hurricanes and floods
  - FEMA: 8 out of the top 10 costliest natural disasters in the United States were caused by coastal storms
- Importance of protecting equipment and infrastructure

U.S. Army Corps of Engineers

# **Issues** Resulting from Climate Change

- Flood maps with new flood zones
  - Risks to human health
  - Risks associated with equipment and structures
- Future sea level rise
  - Risks associated with higher elevations than FEMA maps show
  - Risks associated with predicting future rises in sea level

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# **FEMA** Flood Zones

- Special Flood Hazard Area
- Moderate Flood Hazard Area
- Minimal Flood Hazard Area

# **FEMA Flood Zones** – Special Flood Hazard Area

| Zone | Brief Descriptions |
|---|---|
| V | Areas along coasts subject to inundation by the 1%-annual-chance flood event (100-year flood) with additional hazards associated with storm-induced waves. No Base Flood Elevations (BFEs) or flood depths shown. |
| VE & V1-30 | Areas subject to inundation by the 1%-annual-chance flood event with additional hazards due to storm-induced velocity wave action.  BFEs shown. |
| A | Areas subject to inundation by the 1%-annual-chance flood event. No BFEs or flood depths shown. |
| AE & A1-30 | Same as Zone A with BFEs shown |
| AH | Areas subject to inundation by 1%-annual-chance shallow flooding (usually areas of ponding) where average depths are between 1 and 3 feet.  BFEs shown. |

# **FEMA Flood Zones** – Special Flood Hazard Area

| Zone | Brief Descriptions |
|---|---|
| AO | Areas subject to inundation by 1%-annual-chance shallow flooding (usually sheet flow on sloping terrain) where average depths are between 1 and 3 feet. Average flood depth shown. |
| AR | Areas that result from the decertification of a previously accredited flood protection system that is determined to be in the process of being restored to provide base flood protection. |
| A99 | Areas subject to inundation by the 1%-annual-chance flood event, but which will ultimately be protected upon completion of an under-construction Federal flood protection system. These are areas of special flood hazard where enough progress has been made on the construction of a protection system, such as dikes, dams, and levees, to consider it complete for insurance rating purposes. Zone A99 may only be used when the flood protection system has reached specified statutory progress toward completion. No BFEs or depths shown. |

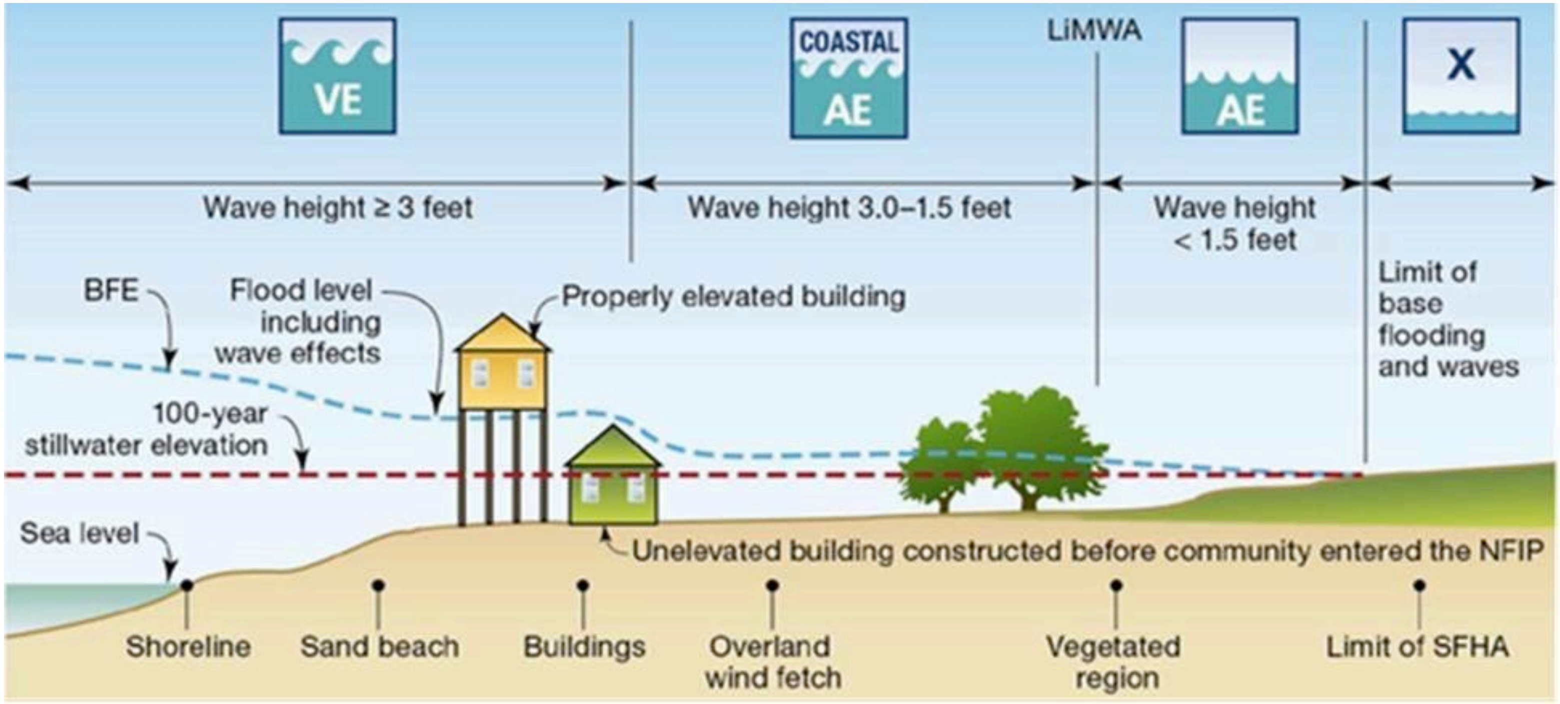
# **FEMA Flood Zones** – Moderate Flood Hazard Area

| Zone | Brief Descriptions |
|---|---|
| B or X (shaded on Flood Insurance Rate Map) | Areas between the limits of the base flood and the 0.2%-annual-chance (or 500-year) flood. |

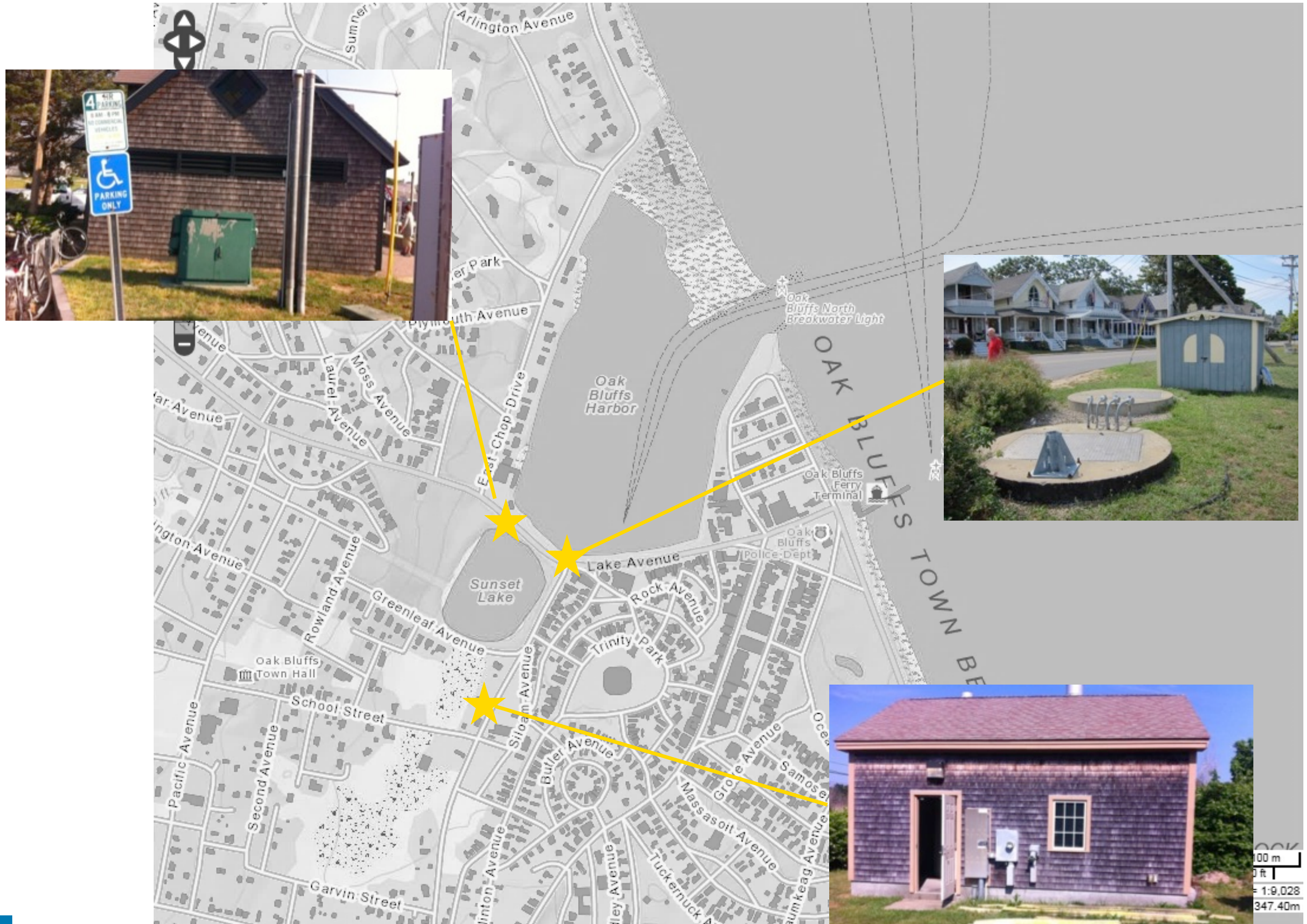
# **FEMA Flood Zones** – Minimal Flood Hazard Area

| Zone | Brief Descriptions |
| --- | --- |
| C or X (unshaded on Flood Insurance Rate Map) | Areas outside the Special Flood Hazard Area and higher than the elevation of the 0.2%-annual-chance flood. |

# **FEMA** Coastal Flood Hazard Zones



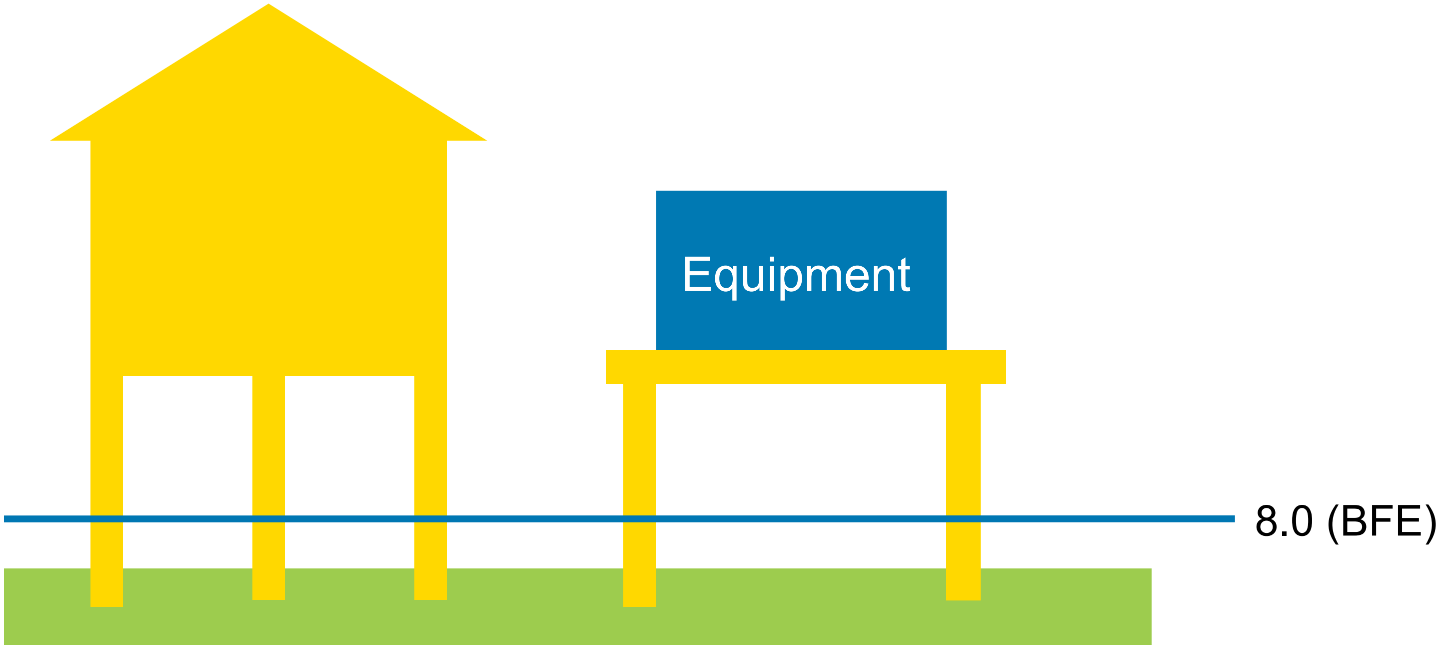
# **Example -** Location of existing pump stations



# **Example - FEMA Flood Map** (Location of existing pump stations)

# **Base Flood Elevation** for Equipment and Structures (Example)

- Base flood elevation (BFE) – 8.0 in North American Vertical Datum of 1988 (NAVD 88)



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# **Sea Level Rise** – General

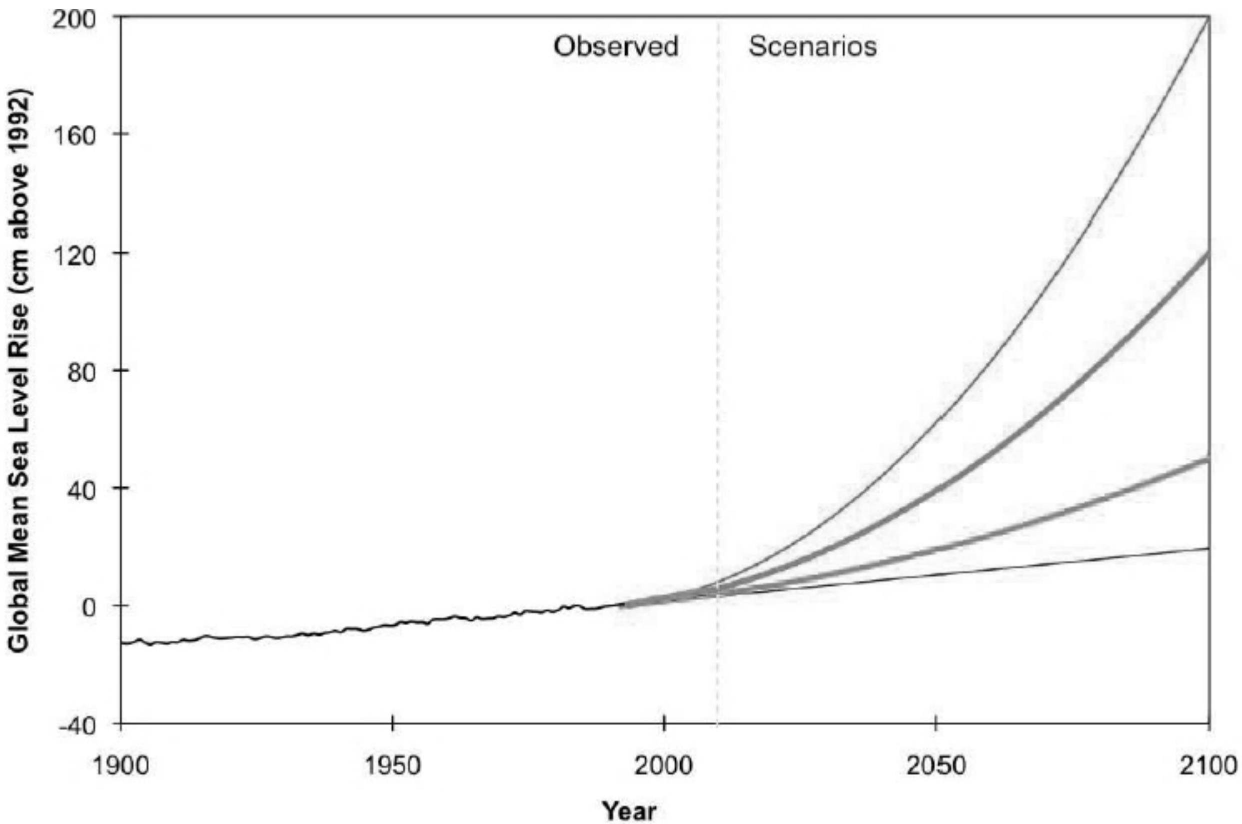
Primary Factors of Sea Level Changes

- Thermal expansion of sea water due to ocean warming
- Melting of glacier / ice sheets

Basis of design

- Equipment are designed to have a 20-year life span
- Masonry and concrete structures are designed to have a 50 to 100-year life span

# **Global Sea Level Rise** Scenarios




**Highest 6.6 ft**

**Intermediate-High 3.9 ft**

**Intermediate-Low 1.6 ft**

**Lowest 0.7 ft**

Figure 4. Four global mean sea level rise scenarios for 1992 to 2100 as contained in *Global Sea Level Rise Scenarios for the United States National Climate Assessment* (Parris et al., 2012). 1992 was used as the beginning point for the analysis because it is the midpoint of the National Tidal Datum Epoch (NTDE), calculated from 1983 to 2001. To account for variability in sea levels, the 19-year NTDE represents the minimum period for which tide gauge observations can be reduced to obtain mean values.

Reference: MA Office of Coastal Zone Management (CZM) – Sea Level Rise: Understanding and Applying Trends and Future Scenarios for Analysis and Planning

# **Sea Level Rise** 20 years from now (Year 2035)

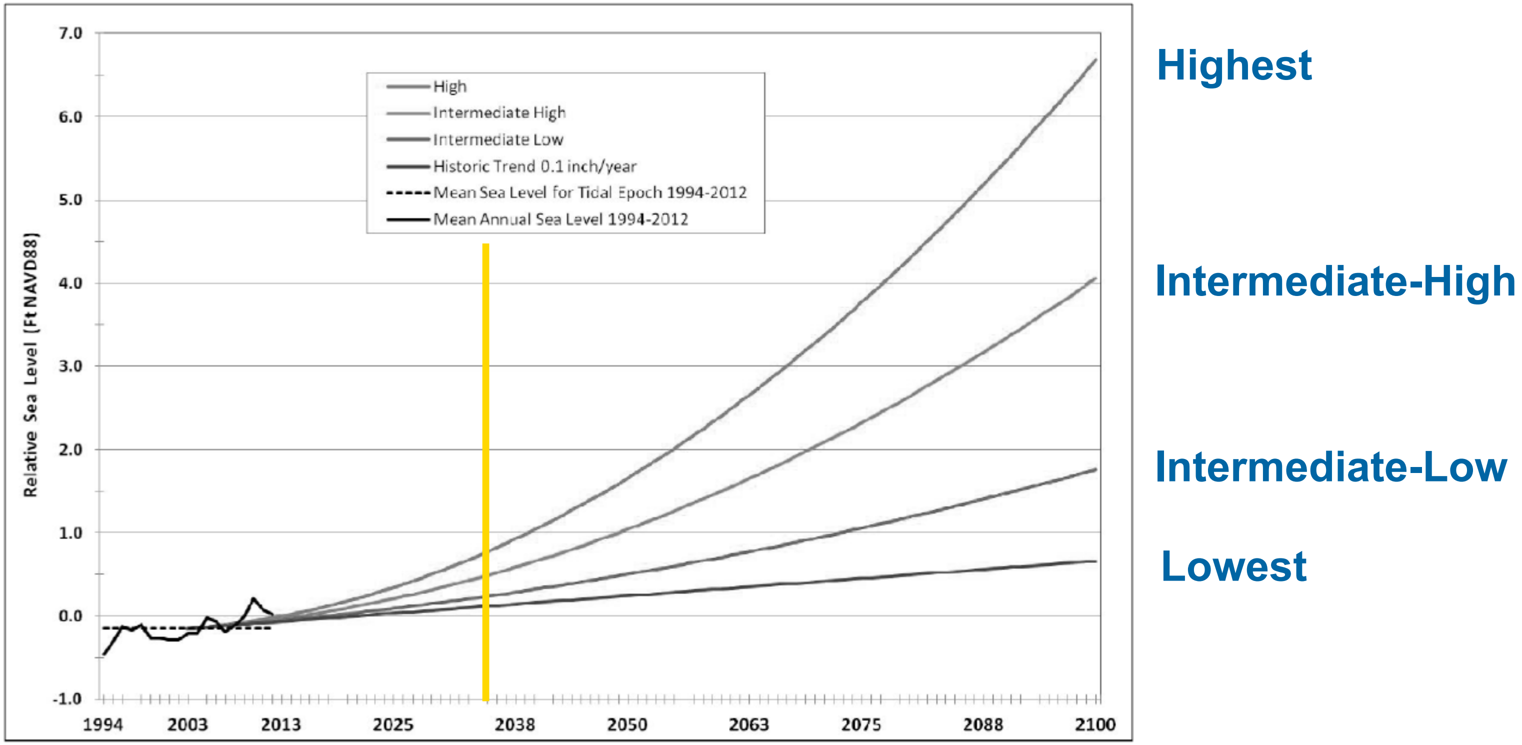
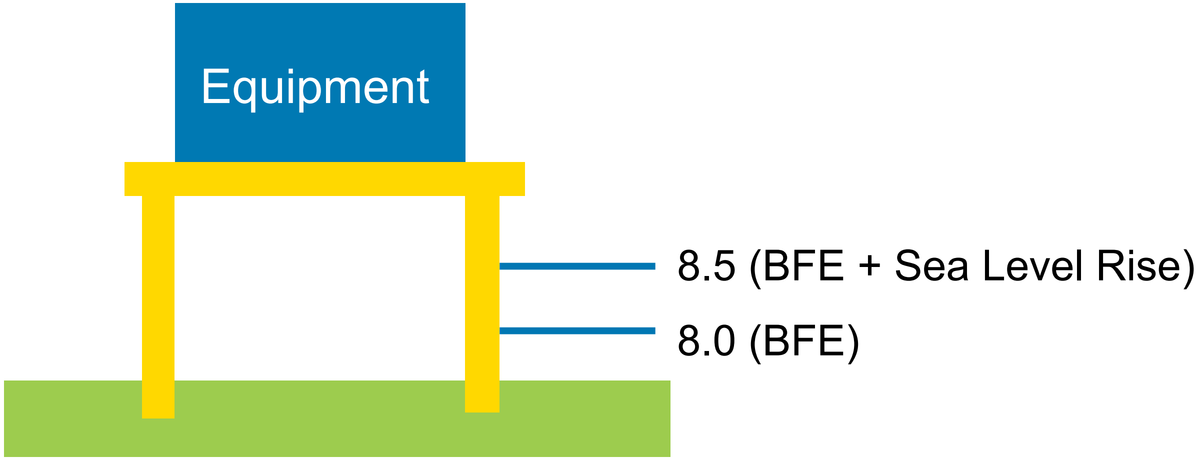



Figure 5. Relative sea level rise scenarios estimates (in feet NAVD88 ) for Boston, MA. Global scenarios from were adjusted to account for local vertical land movement with 2003 as the beginning year of analysis.

| Scenarios | Highest | Int. – High | Int. – Low | Lowest |
|---|---|---|---|---|
| Sea Level Rise | ~0.8 ft | ~0.5 ft | ~0.2 ft | ~0.1 ft |

# **Sea Level Rise** for Equipment – Generator (Example)

- Assumptions – Intermediate-High Scenario with 0.5 ft sea level rise



# **Sea Level Rise** 50 years from now (Year 2065)

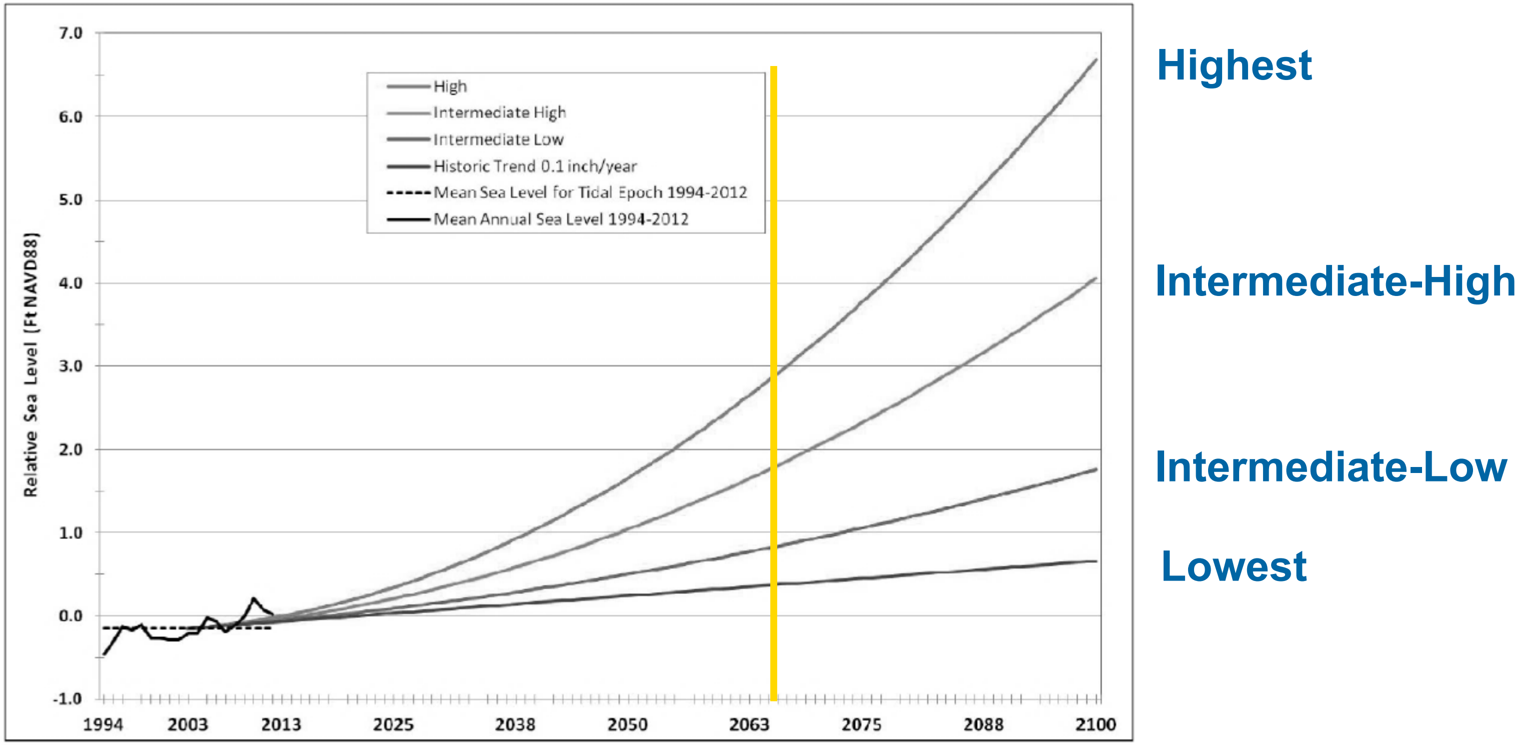
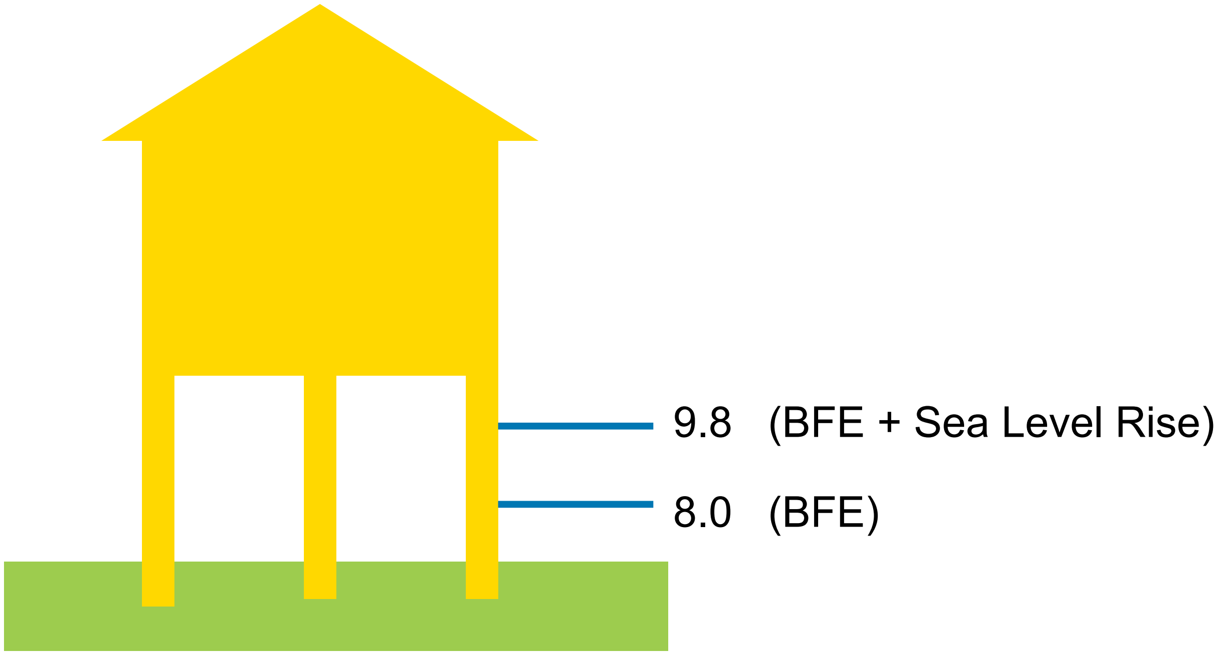



Figure 5. Relative sea level rise scenarios estimates (in feet NAVD88 ) for Boston, MA. Global scenarios from were adjusted to account for local vertical land movement with 2003 as the beginning year of analysis.

| Scenarios | Highest | Int. – High | Int. – Low | Lowest |
|---|---|---|---|---|
| Sea Level Rise | ~2.9 ft | ~1.8 ft | ~0.8 ft | ~0.4 ft |

# **Sea Level Rise** for Structures (Example)

- Assumptions – Intermediate-High Scenario with 1.8 ft sea level rise



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# **Freeboard?** TR-16

TR-16 (Article 3.1.3)

- "Wastewater pumping stations, including **all electrical and mechanical equipment**, should be protected from physical damage by waters **at or above the 100-year flood elevation**, and should remain fully operational and accessible during a 25-year flood. **All entrances and/or unsealable openings of a station should be above the 100-year flood elevation.** These flood elevations should be determined from the best available information from sources such as the Federal Emergency Management Agency, U.S. Army Corps of Engineers, and local regulations and ordinances. Federal and state regulations regarding floodplain and floodway obstructions should be examined. Some agencies, such as USDA Rural Development, may request or require consideration of the 500-year floodplain. Potential effects of long term climate change should also be considered."

# **Freeboard?** ASCE & FEMA

FEMA's "Guidance for Applying ASCE 24 Engineering Standards to 6 HMA Flood Retrofitting and Reconstruction Projects" references ASCE 24 – Flood Resistant Design and Construction

1. Determine classification of structures
   - Category I, II, III and IV
2. Determine which FEMA flood zone the structures and equipment will be located
   - For example, AE zone, Coastal AE zone, etc.
3. Look up corresponding table for minimum elevations for equipment and first floor
   - Include freeboard numbers

# **Freeboard?** Classification of Structures

- Category IV
  - Most critical, essential facilities
  - Hospitals, power generating stations, water systems, etc.
- Category III
  - Less critical facilities
  - Schools, less essential health facilities, other utilities, etc.
- Category II
  - Buildings and structures not under I, III and IV
- Category I
  - Lowest hazard to human life in case of failure
  - Agricultural, temporary and storage facilities

# **Freeboard?** Classification of Structures

**Table 1-3. ASCE/SEI 24-05 Table 1.1 Classification of Structures for Flood-Resistant Design and Construction (Classification same as ASCE 7, *Minimum Design Loads for Buildings and Other Structures*)**

| Nature of Occupancy | Category |
|---|---|
| Buildings and other structures designated as essential facilities including, but not limited to:<br>• Hospitals and other health care facilities having surgery or emergency treatment facilities<br>• Fire, rescue, ambulance, and police stations and emergency vehicle garages<br>• Designated earthquake, hurricane, or other emergency shelters<br>• Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response<br>• Power generating stations and other public utility facilities required in an emergency<br>• Ancillary structures (including, but not limited to, communication towers, fuel storage tanks, cooling towers, electrical substation structures, fire water storage tanks or other structures housing or supporting water, or other fire-suppression material or equipment) required for operation of Category IV structures during an emergency<br>• Aviation control towers, air traffic control centers, and emergency aircraft hangars<br>• Water storage facilities and pump structures required to maintain water pressure for fire suppression<br>• Buildings and other structures having critical national defense functions<br>Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing extremely hazardous materials where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction.<br>Buildings and other structures containing extremely hazardous materials shall be eligible for classification as Category II structures if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2[3] that a release of the extremely hazardous material does not pose a threat to the public. This reduced classification shall not be permitted if the buildings or other structures also function as essential facilities. | IV |

1. Certain agricultural structures may be exempt from some of the provisions of ASCE/SEI 24-05; see Section C1.4.3 of ASCE/SEI 24-05.
2. For the purposes of ASCE/SEI 24-05, minor storage facilities do not include commercial storage facilities.
3. Section 1.5.2 reference is made to ASCE Standard 7-05, not ASCE/SEI 24-05.

# **Freeboard?** Classification of Structures

**Table 1-3. ASCE/SEI 24-05 Table 1.1 Classification of Structures for Flood-Resistant Design and Construction (Classification same as ASCE 7, *Minimum Design Loads for Buildings and Other Structures*)**

| Nature of Occupancy | Category |
|---|---|
| Buildings and other structures that present a low hazard to human life in the event of failure including, but not limited to:<br>• Agricultural facilities[1]<br>• Certain temporary facilities<br>• Minor storage facilities[2] | I |
| All buildings and other structures except those listed in Categories I, III, and IV | II |
| Buildings and other structures that present a substantial hazard to human life in the event of failure including, but not limited to:<br>• Buildings and other structures where more than 300 people congregate in one area<br>• Buildings and other structures with day-care facilities with capacity greater than 150<br>• Buildings and other structures with elementary school or secondary school facilities with capacity greater than 250<br>• Buildings and other structures with a capacity greater than 500 for colleges or adult education facilities<br>• Health care facilities with a capacity of 50 or more resident patients but not having surgery or emergency treatment facilities<br>• Jails and detention facilities<br>• Power generating stations and other public utility facilities not included in Category IV<br>Buildings and other structures not included in Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing sufficient quantities of hazardous materials considered to be dangerous to the public if released.<br>Buildings and other structures containing hazardous materials shall be eligible for classification as Category II structures if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2[3] that a release of the hazardous material does not pose a threat to the public. | III |

III

"…other public utility facilities not included in Category IV"

# **Freeboard** for Utilities and Equipment (Example)

- Assumptions – Structure Category III in AE Zone

Table 2-3. Minimum Elevation of Utilities and Attendant Equipment Relative to BFE or DFE in Zone A

| Structure Category[1] | Flood Hazard Areas |
|---|---|
| I | DFE |
| II | BFE + 1 ft or DFE, whichever is higher |
| **III** | **BFE + 1 ft or DFE, whichever is higher** |
| IV | BFE + 2 ft or DFE, whichever is higher |

1. See Table 1-3 in this document for structure category descriptions.

BFE = base flood elevation

DFE = design flood elevation

ft = feet

Source: ASCE 24-05, Table 7-1

# **Freeboard** for Structures (Example)

- Assumptions – Structure Category III in AE Zone

Table 2-1. Minimum Elevation of the Top of Lowest Floor Relative to BFE or DFE—Flood Hazard Areas Other Than Coastal High Hazard Areas and Coastal A Zones

| Structure Category[1] | Minimum Elevation of Lowest Floor |
|---|---|
| I | DFE |
| II | BFE + 1 ft or DFE, whichever is higher |
| III | BFE + 1 ft or DFE, whichever is higher |
| IV | BFE + 2 ft or DFE, whichever is higher |

1. See Table 1-3 in this document for structure category descriptions.

BFE = base flood elevation

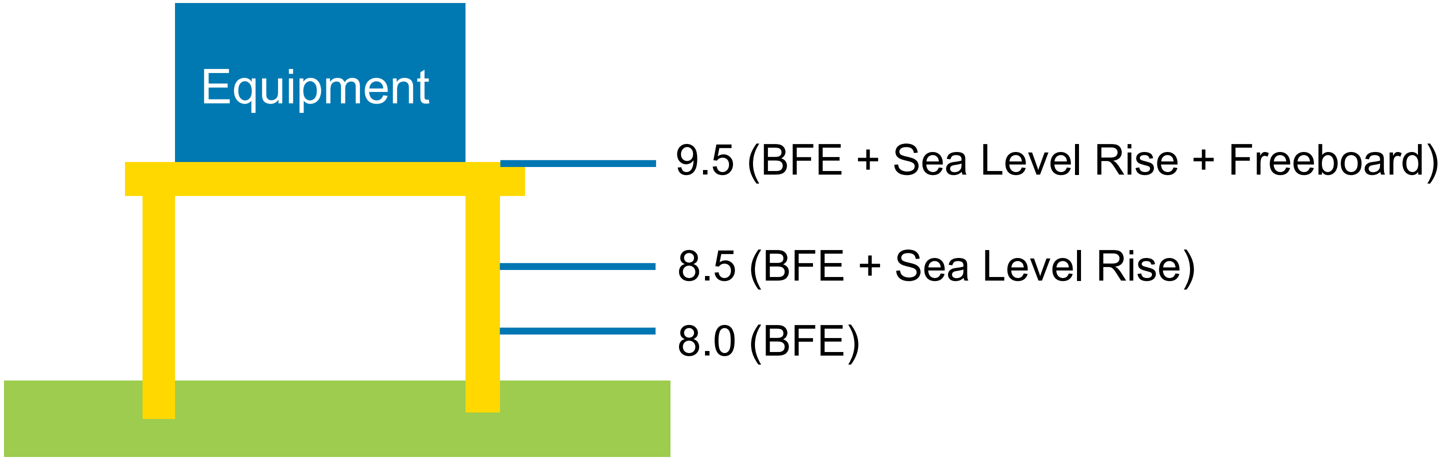
DFE = design flood elevation

ft = feet

Source: ASCE 24-05, Table 2-1

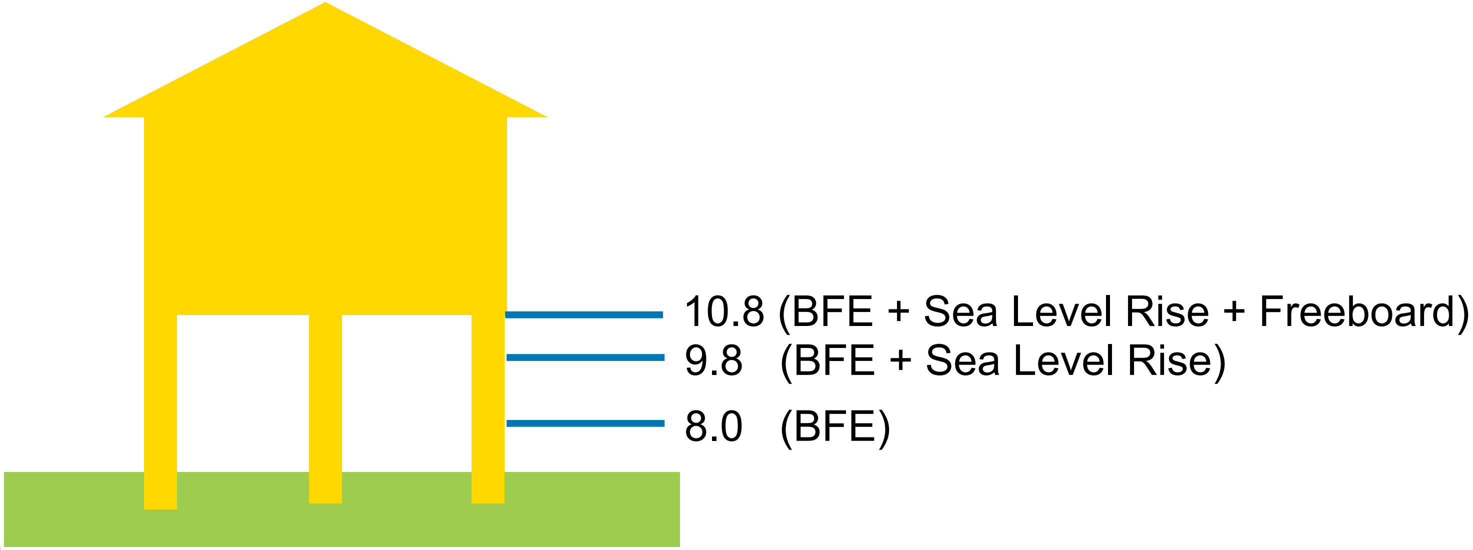
# **How does it all add up?** Equipment - Generator

| Criteria | Elevation / Height |
| --- | --- |
| Base Flood Elevation (BFE, in NAVD 88 datum) | 8.0 |
| Sea Level Rise (Intermediate-High, Year 2035) | 0.5 ft |
| Freeboard (Category III Structure in AE Zone) | 1 ft |
| **Minimum Bottom Elevation of Equipment** | **9.5** |



# **How does it all add up?** Masonry/Concrete Structures

| **Criteria** | **Elevation / Height** |
|---|---|
| Base Flood Elevation (BFE, in NAVD 88 datum) | 8.0 |
| Sea Level Rise (Intermediate-High, Year 2065) | 1.8 ft |
| Freeboard (Category III Structure in AE Zone) | 1 ft |
| **Minimum Elevation of First Floor** | **10.8** |



# Summary

- TR-16 (need to follow guidelines as a designer)
- Determine flood elevation
  - FEMA Maps: Base Flood Elevation (BFE)
- Determine sea level rise
  - MA Office of Coastal Zone Management (CZM)
    - Good practice, some grants require this
- Determine freeboard
  - TR-16 (good practice but not enough detail)
  - ASCE 24 (FEMA recommended, good practice)
- Determine elevation for equipment, utilities and structures
  - BFE + sea level rise + freeboard
  - DFE (Design Flood Elevation set by community)

# Examples of Hazard Mitigation

- Platform for generator located above flood level
- Immersible electrical panel
- Steps to electrical equipment
- Steps to platform for electrical equipment
- Flood panel example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# **Case Study** Our Market Pump Station

Area Served by this Pump Station

- A market
- Residential
- Lone restaurant – remained open after Hurricane Sandy

Problems

- Existing electrical panel is installed too low

Concerns

- Location of panel is in a tourist location
- Visibility of panel at new location


# **Case Study** Our Market Pump Station

Proposed Modifications

- Short term (this project)
  - Remove existing panel
  - Install controls in an immersible enclosure
    - NEMA 6P
    - Heavy duty, stainless steel construction
- Long term
  - Watertight hatch in submersible pump station


# **Case Study** Lake Avenue Pump Station

Area Served by this Pump Station

- Main business/commercial district in Oak Bluffs

Problems

- Main control panel at or below flood level
- Generator connection point inaccessible during flood (Town has portable generator)

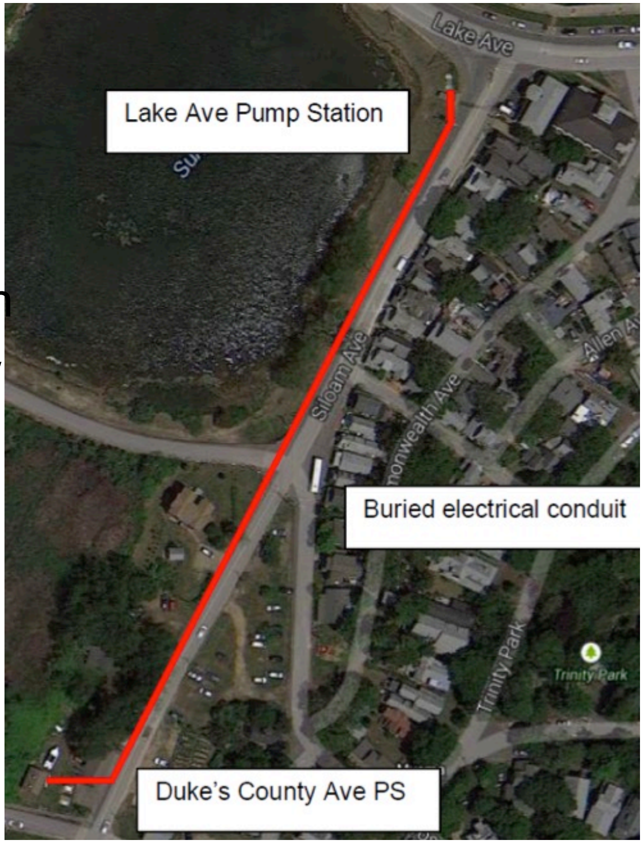
Concerns

- Location of panel is in a tourist location
- Visibility of panel at new location

# **Case Study** Lake Avenue Pump Station

Proposed Modifications

- Short term (this project)
  - Mount new control panel in Duke's County Ave Pump Station
  - Install power conduit from Duke's County Ave Pump Station to Lake Ave Pump Station
  - Provide local shut off at Lake Ave PS in new enclosure
- Long term
  - Watertight hatch in submersible pump station



# **Case Study** Duke's County Avenue Pump Station

Area Served by this Pump Station

- Largest pump station in Oak Bluffs
- Serves nearly the entire sewered population

Problems

- Wooden building in flood zone
- Building inaccessible during flooding event
- Codes prohibit generator to be indoors

Concerns

- Proposed generator in wetland
- Proposed generator location owned by Martha's Vineyard Campground

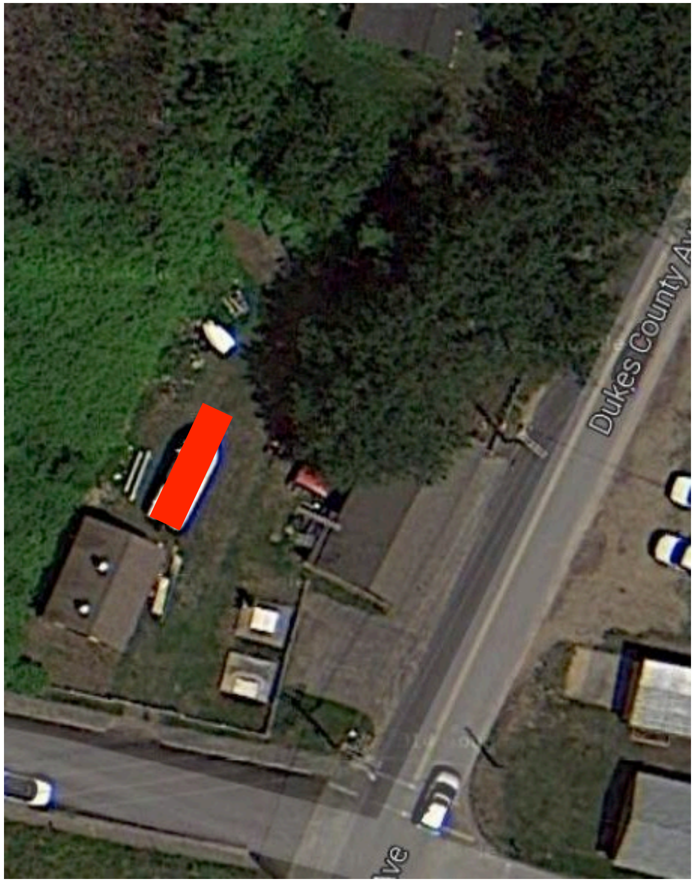
# **Case Study** Duke's County Pump Station

Concerns

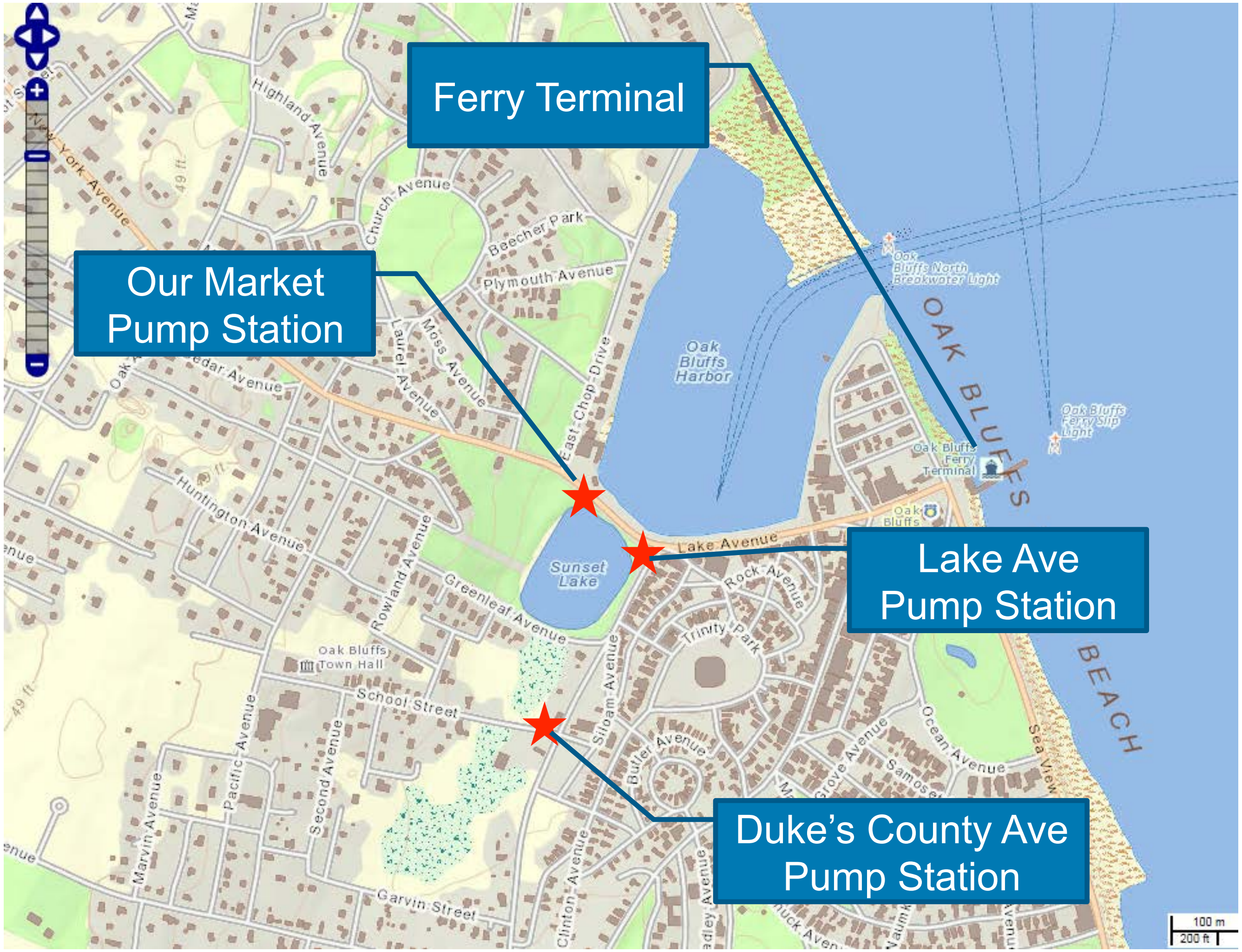
- Wooden building in flood zone
- Building inaccessible during flooding event
- Codes prohibit generator to be indoors

Proposed Modifications

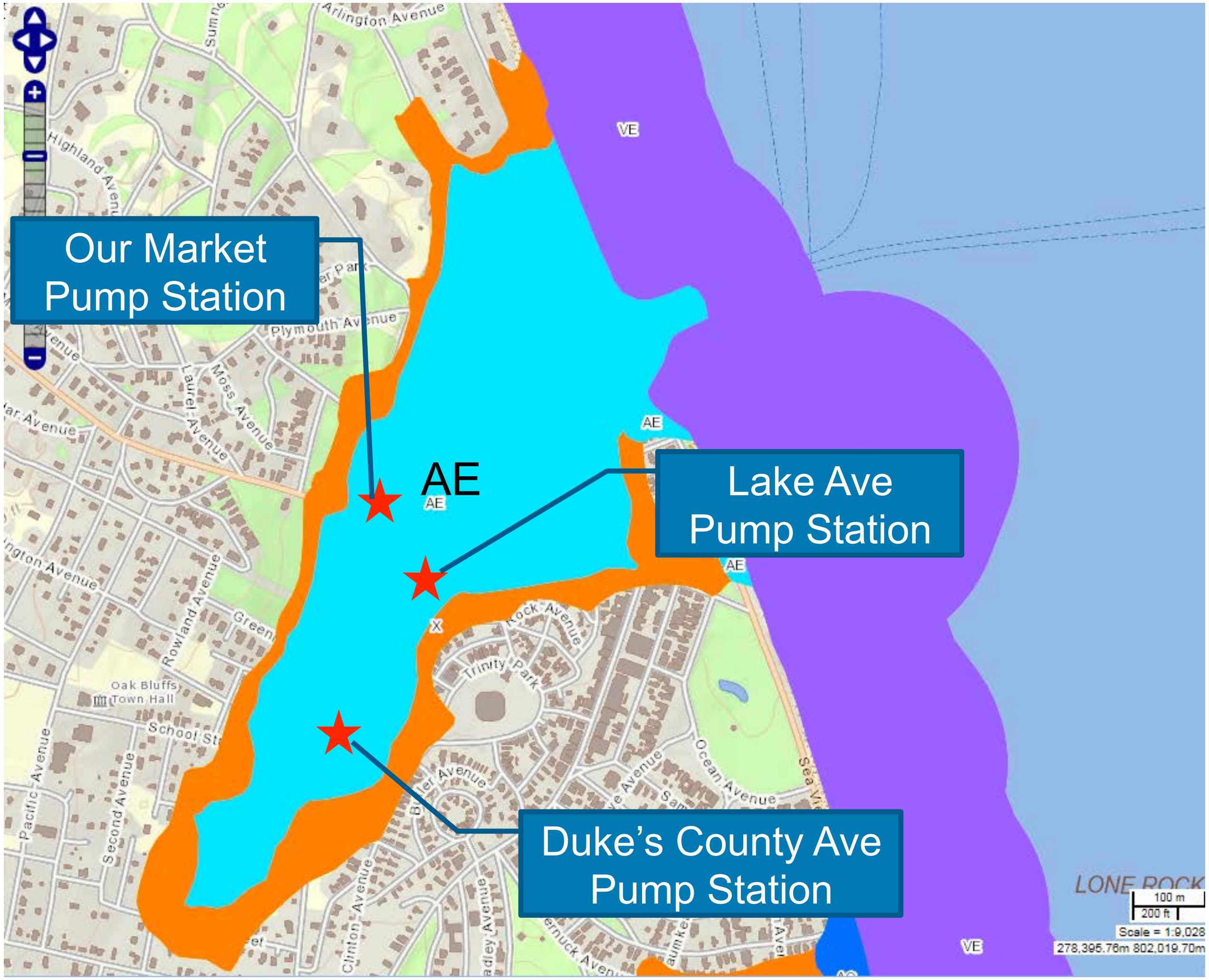
- Short term (this project)
  – Install new diesel generator outdoors with aluminum platform on concrete pad
- Long term
  – Protect electrical panels inside building
  – Accessible to building during flood events



# Location of Existing Pump Stations



# **FEMA Map -** Location of Existing Pump Stations



# Funding and Next Steps

Funding

- Total project costs – $250,000
- EEA/CZM – 75%
- Town – 25%

Next Steps

- Complete final design and construction
- Seek funding to address long term solutions

# **Oak Bluffs** general information

- Northern part of Martha's Vineyard
- Population
  - Approximately 4,500 year round
  - Over 24,000 in summer months
- Small community