ENVISIONING IN SITU SEA LEVEL RISE ADAPTATION STRATEGIES FOR AN URBAN COASTAL COMMUNITY: WAIKĪKĪ, HAWAIʻI

POTENTIAL FLOOD DESIGN ADAPTATION STRATEGIES FOR TWO RESIDENTIAL DEVELOPMENTS
JULY 2020—JANUARY 2022

UNIVERSITY OF HAWAIʻI AT MĀNOA, SCHOOL OF ARCHITECTURE
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CHAPTER ONE

INTRODUCTION
WAIKĪKĪ, HAWAIʻI

Introduction

Waikīkī, the economic hub of Hawaiʻi’s tourism, is a coastal urban area located at low elevation threatened by flooding from sea level rise, high tides, high wave events, groundwater, and heavy rainfall (Figure 1 & Figure 2). One approach to manage sea level rise in the 3.4 square mile (Wikimedia Foundation Inc. 2022) area of Waikīkī is to assume an in-place adaptation strategy, which has yet to be defined and envisioned. The purpose of this research project is to create conceptual design renderings and a written design brief to help visualize preliminary flood adaptation strategies appropriate for Waikīkī while training the next generation of design professionals. The goal of these renderings is to compel discussion, contribute to design guides, inspire pilot projects, and inform new policies that prepare for future flooding.

In 2020, faculty and students at the University of Hawaiʻi (UH) began conducted background research, learning from emerging flood resilience guides, case studies, and the latest sea level rise science from the UH School of Ocean and Earth Science Technology (SOEST). In 2021, this project identified conceptually relevant flood adaptation strategies for Waikīkī, then solicited feedback on these potential approaches from over 70 diverse, locally-based stakeholders, and compiled the feedback into a report. In 2021 and 2022, the report’s findings were used to create two site-specific urban and architectural renderings of a resilient, economically vibrant Waikīkī with flood adaptation strategies. This work was presented publicly to over 120 stakeholders and summarized within this booklet.

Acknowledgments

Principal funding for this project was provided by the Hawaiʻi Sea Grant’s Biennial Grant 2020–2022 and the Office of Naval Research. We would like to thank Shellie Habel, PhD, Hawaiʻi Sea Grant, whose sea level rise research complements this project. We would like to thank Melanie Lander, Hawaii Sea Grant, for outreach organization and report editing.
CHAPTER TWO

SITE INFORMATION + STUDY AREAS
Figure 3. Map of Waikīkī w/ +3.2' SLR-XA & Land Use Ordinance

City and County of Honolulu (CCH) Land Use Ordinance
- Apartment
- Apartment Mixed Use
- Resort Mixed Use
- Public

Sea Level Rise Exposure Area (SLR-XA) Map
- +3.2' SLR-XA
- Waikīkī Special District


SITE SELECTION + CRITERIA

One of the first steps towards creating site-specific urban and architectural renderings was to establish the following criteria to select prototypical buildings or land parcels on which a variety of flood adaptation strategies could be evaluated and illustrated.

1. Identify areas estimated to be flooded soonest. This aligns with former Mayor Kirk Caldwell’s Directive 18-2, to identify 3.2 feet SLR as a planning benchmark by mid-century (City and County of Honolulu, Office of the Mayor 2018). This project referenced the extent of modeled chronic flooding on the State of Hawai‘i Sea Level Rise Viewer, which includes passive flooding, annual high wave flooding, and coastal erosion (Figure 3).

2. Identify a variety of building program types, including high-rise and low-rise residential, commercial, retail, and hospitality by referring to the City and County of Honolulu (CCH) Land Use Ordinance map of Waikīkī.

3. Identify buildings with at-grade or below-grade spaces that appear vulnerable to flooding based on our observation and reasoning.

4. Identify older buildings for retrofit, recognizing that they are more likely to be redeveloped, in contrast to more recently built structures. The original date of construction and flood zone were obtained from the Property Information Report and Real Property Information Assessment via the CCH Parcel and Zoning Information website (CCH, n.d.).

One of the challenges related to sea level rise is groundwater inundation. It is expected to produce some of Honolulu’s most problematic SLR flooding, with the ability to evade coastal barriers designed to mitigate surface-water inundation as it is lifted through the ground surface (Rotzoll and Fletcher 2013). The lack of adequate drainage in Waikīkī is already problematic when the highest marine water levels of the year occur, in conjunction with ocean swell and/or rain, causing storm drain backflow.

Through this process, five potential sites in Waikīkī were identified (Figure 3), and Site 1 in west Waikīkī and Site 2 mauka (meaning, towards the mountains in Hawaiian) Waikīkī are discussed in this booklet. Both sites are located along Ala Wai Boulevard, which delineates the inland extent of the community of Waikīkī, runs parallel to the Ala Wai, and selected based on their significance as residential communities.

The other three sites were identified for potential further research. The next steps for this project are to continue this design research with new graduate research assistants (GRAs) and staff, at a new site: a beachfront building and open space area.

Site #1: West Waikīkī along Ala Wai Boulevard

Currently West Waikīkī’s predominant building types are high-rise residential towers and three-story residential walk-up buildings (Castillo 2022). At Site 1 in West Waikīkī, the team focused on the adaptation of a typical low-rise residential walk-up building at 1627 Ala Wai Boulevard (Figure 4) where this site is projected to experience extensive flooding with 3.2 feet SLR (Figure 3). The three existing low-rise residential walk-ups have at-grade spaces at risk for flooding. Originally constructed in 1950, these buildings were selected due to the likelihood of future redevelopment. As discussed in Chapter 3, the focus of Site 1’s renderings are the retrofit of these three low-rise residential walk-up buildings by 2050 and new construction by 2100 with rising sea level.

Site #2: Mauka Waikīkī along Ala Wai Boulevard

The second site is in the mauka area of Waikīkī, where designs were explored for the adaptation of a typical high-rise residential building with below-grade parking at 2085 Ala Wai Boulevard (Figure 5). As shown with Figure 3, extensive sea level rise induced flooding of this site and its surrounding area is projected with 3.2 ft SLR by the Hawai‘i Sea Level Rise Viewer (Hawai‘i Climate Change Mitigation and Adaptation Commission 2017). Most of the buildings in this area are residential with limited mixed-use and commercial buildings. It is common to find this type of high-rise residential building with below-grade parking with large screened or unscreened openings along this section of Ala Wai Boulevard. Given that the building was built in 1967, its age and state of the structure being intact, indicates this building’s useful life might be extended to 2100 with retrofits.
CHAPTER THREE

UNDERSTANDING DESIGN FLOOD ELEVATIONS + WATER LEVELS
SLR PROJECTIONS & GUIDANCE

The project team surveyed climate change adaptation guidelines from Honolulu, Boston, New York, and Miami focusing on future decadal sea level rise estimates, building elevation guidance, and adaptation strategies. Currently, the most relevant information regarding SLR and the adaptation of the built environment in Hawai‘i is included in the City and County Honolulu “Climate Adaptation: Background Research, International Best Practices and Local Initiatives” (2020) and “Climate Adaptation: Design Principles for Urban Development” (2020) documents prepared by SSFM International Inc. and Associated Regional and University Pathologists (ARUP). Honolulu’s Climate Adaptation document (2020) recognizes that municipalities are exploring building design requirements for greater inundation as a result of SLR and more extreme rainfall events, but does not provide specific guidance such as proposed design flood elevations. The City of Boston “Coastal Flood Resilience Design Guidelines” (City of Boston Planning and Development Agency 2019) and New York City’s “Climate Resiliency Design Guidelines” (NYC Mayor’s Office of Recovery and Resiliency 2020) include decadal projections of SLR and suggested freeboard, and informed this project’s site-specific future design flood elevations (defined and discussed below) and flood adaptation strategies.

Based on discussions with Waikīkī and Honolulu stakeholders, design teams are seeking guidance specific to Hawai‘i. Therefore, this project proposes future design guidance relative to local projections that accounts for sea level rise and king tides.

Local Tides and Sea Level Rise Projections

The following definitions are useful in understanding sea level rise and king tides in Waikīkī:

- Mean Higher High Water (MHHW): the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch (NOAA, n.d.). Relative to local mean sea level (LMSL), at the Honolulu Tide Station, MHHW is located 0.33 m (1.08 ft) above LMSL. The sea level rise scenarios are measured above MHHW.
- Mean Sea Level (MSL), the arithmetic mean of hourly heights observed over the National Tidal Datum Epoch (NOAA, n.d.).

Local mean sea level (LMSL): for Waikīkī, mean sea level at the Honolulu Tide Station, 0-foot. (NOAA, n.d.). The Federal Emergency Management Agency (FEMA) FIRM Base Flood Elevations (BFE) are measured from LMSL. In comparison to other places around the U.S., Hawai‘i will experience higher levels of SLR (Sweet et al. 2017). Sea level rise and high tide flooding projection relative to LMSL should be used in future local planning efforts versus global mean sea level (GMSL) rise trends (Habel et al. 2020).

The Honolulu Tide Station (see Table 1) 2’ 0” LMSL rise by year 2050, and 6’ 8” LMSL rise, by year 2100, as planning benchmarks based on the (older) NOAA Report intermediate-high scenario (Sweet et al. 2017).

- Global mean sea level (GMSL): the average height of the entire ocean surface (NASA, 2022).

This project used data from the 2017 NOAA report on “Global and Regional Sea Level Rise Scenarios for the United States,” which describes six SLR scenarios (i.e., low, intermediate-low, intermediate, intermediate-high, high, and extreme) with projections of future SLR per decade for coastal-risk planning (Sweet et al. 2017). Because of the perceived low-risk tolerance for residential buildings, the project team referenced the intermediate-high scenario, which represents a 1% probability, high consequence scenario (Sweet et al. 2017). This is similar to Miami Dade’s approach in their “Sea Level Rise Strategy Plan,” which also refers to the NOAA intermediate-high scenario (Miami Dade County 2021).

Toward the conclusion of this research in 2022, an update to the 2017 document was published as “Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities along U.S. Coastlines” (Sweet et al. 2022). In this 2022 document, the intermediate-high scenario projections for sea level rise are slightly lower than those used in this research. Future research should use the 2022 document sea level rise scenarios and the LMSL rise projections for specific tide stations (e.g., Waikīkī) on the new Interagency Sea Level Rise Scenario Tool website (Interagency Task Force, n.d.).

Using the NOAA Office for Coastal Management Sea Level Rise Data (NOAA, 2022), similar graphics were created to visualize the areas impacted in Waikīkī from two feet of SLR (Figure 6), up to six feet of SLR (Figure 7).

Table 1. Local Mean Sea Level (LMSL) Rise projections at 2050 & 2100 for the Honolulu Tide Station using the NOAA Intermediate-High scenario

Source: Sweet, W.V. et al., 2022.
Figure 7. Map of Waikīkī w/ 3.0ft-6.0ft SLR. Source: NOAA Office for Coastal Management, 2022.

Base Flood Elevations (BFE) & Design Flood Elevations (DFE)

The following definitions are useful in understanding the potential new building design requirements for greater flooding:

- **Base Flood Elevation (BFE):** “the elevation of surface water resulting from a flood that has a 1% chance of equaling or exceeding that level in any given year…” (FEMA Protecting Building Utility Systems from Flood Damage, n.d.) relative to the datum specified on a community’s Flood Insurance Rate Map (FIRM) (e.g., LMSL in Honolulu). The BFE is the National Flood Insurance Program’s (NFIP) minimum elevation used for design and construction of buildings. Areas affected by the base flood are shown as Special Flood Hazard Area (SFHAs) or Flood Insurance Rate Maps (FIRMs). As of 2022, FEMA-BFEs are based on historical flood data and do not take into account any additional water caused by future SLR (NFIP, 2022) (Figure 8).

- **Freeboard:** An added margin of safety expressed in feet above a specific flood elevation, usually the BFE. Some regulations require a freeboard. Freeboard can account for unknown factors, future development, and floods higher than the base flood. (FEMA Protecting Building Utility Systems from Flood Damage, n.d.) (Figure 8).

- **Design Flood Elevation (DFE):** The elevation of the design flood relative to the datum specified on a community’s flood hazard map (e.g., LMSL in Honolulu). This elevation is the higher of the base flood or the value designated for a flood hazard area on a community flood map or otherwise designated (Figure 8).

- **Flood zones:** Geographic areas that the FEMA has defined according to varying levels of flood risk based on the severity or type of flooding (FEMA, n.d.). Depicted on community FIRM.

This project proposes a set of SLR-adjusted building design flood elevations for 2050 and 2100. The 2021 FEMA-BFE and DFE for the CCH 2018 International Building Code (IBC), requires most buildings to be designed with one foot of freeboard above the BFE (CCH 2020). (ASCE 2015). However, the amount of freeboard added depends on a building’s flood design class as categorized by the American Society of Civil Engineers (ASCE) Standard 24-14 (ASCE 2015). The ASCE Standard 24-14 is referenced in the 2018 IBC.

In Hawaii’s, the public may look up a parcel on the State of Hawaii Flood Hazard Assessment Tool (State of Hawaii DLNR, n.d.) to determine the FEMA flood zone and BFE. For example, Site 1 is in FEMA flood zone AE (high risk) with a BFE six feet above LMSL. This means that the building’s first floor should be raised no less than six feet above LMSL or spaces below this height should be wet floodproofed and/or relocated to higher levels to accommodate potential flood risk. Wet floodproofing allows flood waters to enter enclosed areas of the building, made with flood resistant material, to reduce the effects of hydrostatic pressure on the building (FEMA n.d.).

**SLR-Adjusted BFE and DFE**

Similar to the City of Boston (2019) and New York City (2020), this project proposes a set of site-specific SLR-adjusted design flood elevations. First, the amount of LMSL rise projected for a specific year is added to the current MHHW level. Given that the magnitude and frequency of king tide events are estimated to increase in the future (Habel et al. 2020), the estimated amount of water from a future king tide event is also added (Table 2).

The SLR and king tides are added to the present-day BFE to determine a new potential SLR-adjusted BFE. The team acknowledges that in the future, the 1% annual chance flood amount for a specific flood zone may increase (Sweet et al. 2017) and a higher BFE would likely be established.

Next, freeboard is added (one foot for retrofits and two feet for new construction), similar to the Boston Design Guidelines for Retrofit or New Construction Projects (City of Boston Planning and Development Agency 2019). The LMSL rise, king tides, BFE, and freeboard are added to determine a new potential SLR-adjusted DFE. This process may be replicated at other coastal parcels in Waikiki or Honolulu.

Unlike current FEMA flood maps or building codes that do not account for rising sea levels, the need for higher DFEs in the future will be necessary. Therefore, this project hopes that the findings of this research project may contribute to future design guides, pilot projects, and new policies that prepare for SLR.

**Table 2.** Estimated sea level rise and king tide scenarios for Honolulu Tide Station at NOAA Intermediate & Intermediate-High scenarios.

<table>
<thead>
<tr>
<th>NOAA RSLR Scenario</th>
<th>Intermediate</th>
<th>Intermediate High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2050</td>
<td>2100</td>
</tr>
<tr>
<td>MHHW²</td>
<td>45 cm</td>
<td>131 cm</td>
</tr>
<tr>
<td>King Tide³</td>
<td>19 cm</td>
<td>26 cm</td>
</tr>
<tr>
<td>Water Table⁴</td>
<td>60.1 cm</td>
<td>60.1 cm</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>124.1 cm, 4.1 ft</strong></td>
<td><strong>217.1 cm, 7.1 ft</strong></td>
</tr>
</tbody>
</table>

Sweet et al. (2017) give three versions of each scenario corresponding to the 17th (low), 30th (median), and 83rd (high) percentile of the climate-related sea level projections consistent with the GMSL scenario. We use the 83rd percentile due to low risk tolerance of community design.

³ Relative to the year 2000.

⁴ Water table, 2 ft clearance to provide some dry depth.

Table 2. Estimated sea level rise and king tide scenarios for Honolulu Tide Station at NOAA Intermediate & Intermediate-High scenarios.
CHAPTER FOUR

ADAPTATION STRATEGIES
ADAPTATION STRATEGIES

In order to determine the adaptation strategies best suited to Waikīkī’s conditions, the project sought the input of a diverse set of local stakeholders. The project team collated adaptation strategies through a survey of national guidance documents and performed an initial categorization of those with broad applicability to Hawaii (i.e., responsive to hazards present within the state).

In the summer of 2021, five workshops were held with 71 stakeholders including businesses, landowners, government employees, elected officials, residents, consultants, urban planners, and design professionals (Figure 9). Each event included a summary of sea level rise science followed by examples of sea level rise adaptation strategies determined to have broad relevance to Hawaii. Based on their professional and lived experiences in Waikīkī, participants provided feedback on whether the strategies were familiar to them and gauged each of their applicability to Waikīkī’s conditions in quantitative surveys. Subsequently, facilitated break-out groups captured qualitative feedback about each strategy. The strategies deemed to be applicable to Waikīkī were applied to the design process and depicted in the project’s renderings and visualizations.

In 2022, the renderings were publicly presented and discussed with guest experts and an audience of over 120 people, and are available online (Figure 9). Surveys captured the audiences’ most favored adaptation strategies and comments, which were compiled into publicly available reports (Peppard 2022) for use by future design teams and policy makers.

Figure 9. 2021 Stakeholder Report (left) & 2022 Stakeholder Report (right) Source: Peppard, 2022.
Building Adaptation Strategies

- Elevate on Open Foundation
- Elevate on Fill
- Elevate Exterior Circulation
- Elevate Interior Circulation
- Re-Purpose Below-Grade Spaces
- Relocate Ground Floor Use
- Re-Purpose At-Grade Spaces
- Relocate Critical Systems
- Wet Floodproofing
- Dry Floodproofing
- Building w/ Flood-Resistant Materials

Figure 10. Building Adaptation Strategies
Transportation, Open Space, and Utility Adaptation Strategies

- Raised Streetscape
- Resilient Streetscape
- Cisterns & Water Collection
- Floodable Open Spaces
- Ecological Water Treatment
- Elevate Critical Equipment
- Protect & Replace City Utilities
- Below-Grade Water Storage

Figure 11. Transportation, Open Spaces, and Utility Adaptation Strategies
A building with an open foundation may be elevated on piles, piers, posts or columns. Depending on a building’s location within a flood zone, current code dictates that the first occupied floor of the building is elevated at or above the BFE (ASCE 2015). In the future, with rising sea levels the first occupied floor should be elevated above the SLR-BFE (City of Boston Planning and Development Agency 2019).

In Waikīkī, some existing buildings are raised on an open foundation with at-grade parking tucked beneath the building (Figure 12).
A building may also be elevated on fill by using appropriate structural fill. Similar to the strategy to "Elevate on Open Foundation," the first occupiable floor of the building should be elevated at or above the BFE (ASCE 2015). With sea level rise, the first occupiable floor should be elevated above the SLR-DFE (City of Boston Planning and Development Agency 2019).

In Waikiki, some buildings appear to be elevated on fill (Figure 13). Based on observation, these types of buildings typically incorporate external ramps or stairs leading up to the first floor.
Circulation to reach the elevated first floor level is provided outside the building through exterior walkways, ramps, or stairs. Contextual design measures should contribute to visual interest, break up the scale of larger surfaces and add to character. For example, the Kaka’ako Whole Foods Market in Honolulu, Hawai‘i uses both external ramps and stairs to reach the elevated first floor of the building (Figure 14).

As recommended by the City of Boston Design Guidelines, “design measures like planted areas, seating, lighting and contextually appropriate materials are used to contribute to visual interest, break up the scape of larger surfaces, and add to neighborhood character” (City of Boston Planning and Development Agency 2019).

Figure 14. Example of existing elevated exterior circulation with integrated seating at Whole Foods Market at Ward in Honolulu. Source: Google Maps.
As recommended by the City of Boston Design Guidelines for buildings that have high first floor ceilings, the floor may be elevated or reconstructed at or above the SLR-DFE to protect that floor from flood risk. (City of Boston Planning and Development Agency 2019). Circulation to reach the elevated first floor level from an at grade entry area may be provided by internal ramps, stairs, etc.

Currently, some places in Waikīkī, Hawai‘i (Figure 15) and Venice, Italy (Figure 16) already do this at the ground floor level. Circulation is possible via the design and use of internal stairs and ramps.

Figure 15. Example of existing interior circulation via stairs at commercial building in Waikīkī. Source: Derek Aegerter.

Figure 16. Example of interior circulation in Venice, Italy. Source: Archivibe/ "The Renovation of the Fondazione Querini Stampalia is a great example of how Master Carlo Scarpa integrated the new with the old."
Existing below-grade and below the SLR-DFE space that is subject to flooding and was previously used for storage or parking can be filled to the nearest adjacent grade to reduce hydrostatic pressure on the structure. As recommended by the City of Boston Design Guidelines, actions to also wet floodproof (See Wet Floodproof) spaces below the SLR-DFE are recommended. Spaces below the SLR-DFE should be used only for parking, storage, or access (City of Boston Planning and Development Agency 2019).

Spaces displaced may be moved to an existing or additional floor on top of the building (highlighted in orange), if the existing structure can be retrofitted to take on the additional load (Figure 18).

Figure 17. Addition of new floor to accommodate repurpose of spaces at or below-grade. Source: Hacin and Associates/FP3.

Figure 18. Water storage used in space below the DFE. Source: Paul De Ruiter Architects/Museumpark.
Building utility systems, including electrical and mechanical equipment, should be protected from flood risk to avoid costly damage, safety risks, and loss of critical building functions during a flood event. This action should be a high priority consideration by building owners to allow building operation to continue during flooding events. For example, this can be done by either elevating the relevant equipment on a platform or higher floor (Figure 19).

Figure 19: Example of elevated critical systems. Source: FEMA Protecting Building Utility Systems from Flood Damage.
Wet Floodproofing

Wet floodproofing is an adaptation measure that allows floodwaters to enter "the enclosed areas of the house and to quickly reach the same level as the floodwaters outside," thereby greatly reducing the effects of hydrostatic pressure on the building (FEMA, 2021). In Waikiki, an example of this is a below-grade parking lot with openings (Figure 21).

Current FEMA standards recommend that the minimum requirements for Wet Floodproofing include (FEMA 2014):

- At least two wall openings for each enclosed area; located on two different walls.
- If the house has more than one enclosed area, openings must installed in the exterior walls of each enclosed area that floodwaters can enter directly from outside.
- The total area (size) of all openings for each enclosed area must be equal to at least 1 square inch for every square foot of floor space in the enclosed area.
- The bottom of each opening must be no higher than 1 foot above the ground directly below the opening (Figure 20).

Figure 20. Example of flood vents and openings in below-grade spaces. Source: The Construction Specifier/"When Wetter May be Wiser: Designing for resilience in areas subject to flooding."

Figure 21. Below-grade parking with openings at residential building in Waikiki. Source: Google Maps.
Dry Floodproofing is an adaptation measure that prevents the entry of floodwaters. Based on the City of Boston Design Guidelines, dry floodproofing may include the following (City of Boston Planning and Development Agency 2019).

- Watertight enclosures for openings, doors, windows, and floors including shields and barriers, often requiring human intervention prior to a storm event. Types of flood shields include: sliding, lift-out, modular panel, bolt-on hinged, and automatic. An example of this is shown at Whitney Museum in New York (Figure 22).
- Membranes and sealants to reduce seepage of floodwater through walls and utility conduits.
- Structural reinforcement to wall assemblies so that they can resist hydrostatic pressure, flotation, or collapse.
- Pumping and drainage systems with backup power to control water intrusion.
- Backflow or check valves to prevent the entrance of water or waste through plumbing systems.
- Flood doors and egress requirements.

Figure 22: Example of flood barriers erected on site to protect ground floor at the Whitney Museum in New York. Source: Cooper Robertson/"White Paper: Flood Mitigation in Museum Design."
The National Flood Insurance Program (NFIP) defines flood-resistant materials as "any building product [material, component or system] capable of withstanding direct and prolonged contact with floodwaters without sustaining significant damage." All construction below the BFE is susceptible to flooding and must consist of flood damage-resistant building materials (FEMA 2008).

The chart on the right lists acceptable and unacceptable materials that can be used as a flood resistant material in a building’s construction (Figure 23).

<table>
<thead>
<tr>
<th>Structural Flooring Materials</th>
<th>Finish Flooring Materials</th>
<th>Structural Walls and Ceiling Materials</th>
<th>Finish Wall and Ceiling Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Concrete</td>
<td>• Clay tile</td>
<td>• Brick face, concrete, or concrete block</td>
<td>• Glass blocks</td>
</tr>
<tr>
<td>• Naturally decay-resistant lumber</td>
<td>• Ceramic or porcelain tile</td>
<td>• Cement board/fiber-cement board</td>
<td>• Metal cabinets or doors</td>
</tr>
<tr>
<td>• Pressure-treated plywood</td>
<td>• Terrazzo tile</td>
<td>• Pressure-treated plywood</td>
<td>• Latex paint</td>
</tr>
<tr>
<td>• Vinyl tile or sheets</td>
<td></td>
<td>• Solid, standard structural lumber (2x4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Non-paper-faced gypsum board</td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<tr>
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<th>Finish Flooring Materials</th>
<th>Structural Walls and Ceiling Materials</th>
<th>Finish Wall and Ceiling Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Engineered wood or laminate flooring</td>
<td>• Engineered wood or laminate flooring</td>
<td>• Fiberglass insulation</td>
<td>• Wood cabinets and doors</td>
</tr>
<tr>
<td>• Oriented-strand board (OSB)</td>
<td>• Carpeting</td>
<td>• Paper-faced gypsum board</td>
<td>• Non-latex paint</td>
</tr>
<tr>
<td></td>
<td>• Wood flooring</td>
<td>• Oriented-strand board (OSB)</td>
<td>• Particleboard cabinets and doors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Wallpaper</td>
</tr>
</tbody>
</table>

Figure 23. List of acceptable and unacceptance flood resistant materials from National Flood Insurance Program (NFIP). Source: FEMA Homeowner’s Guide to Retrofitting.
Raising roadways can be an effective strategy to control flooding and maximize the usability of roads for evacuation, emergency response, and general mobility during flooding events. Suitable for large areas being developed to optimize the sequence of actions.

In Miami, Florida, a street that had previously experienced flooding was raised, while existing business show the difference in the elevation change (Figure 24).

Figure 24. Example of elevated street in Miami, Florida. Source: Dolan Eversole.
Per CCH’s guidelines, the space between the building façade and street should mitigate the impact of the elevation change on the public realm or right-of-way (ROW) by including amenities such as flood-resistant plantings, sidewalks, seating, trees, awnings, and other placemaking elements or design considerations. Because of the jurisdictional transitions between buildings and the streetscape, collaboration between public and private entities will be required, as well as consideration to the current standards and regulations such as the Americans with Disabilities Act (ADA) Accessibility Guidelines. (City and County Honolulu: Climate Adaptation Design Principles for Urban Development, 2020)

Figure 25 shows an example of a resilient streetscape including vegetation in the transition zone and two ways to access an elevated building entrance via a gradual ramp or a staircase.
Future storm drain backflow and a higher groundwater table may limit rainwater runoff conveyance and infiltration. Rainwater may be harvested and stored in rain barrels or cisterns and either reused on-site or discharged to the sewer after a storm event.

Figure 26 shows rainwater storage in cisterns for non-potable water uses such as irrigation.

Figure 26. Example of a cistern in housing community in Seattle, Washington, used to collect and store rainwater and stormwater on-site for later use or delayed discharge. Source: Wendy Meguro.
Included in “City and County Honolulu: Climate Adaptation Design Principles for Urban Development.”

“[For] larger flooding events, sites can also be designed to include features that provide both function and flood retention, such as floodable parking structures and plazas, or wetland areas that can accommodate greater flows. Likewise, on-site rainwater harvesting can be used for the dual benefit of flood mitigation and water conservation.”

(COH Climate Adaptation Design Principles for Urban Development, 2020)

An example by Public Space includes rainwater collection ponds used as amphitheatres, basketball and volleyball courts, or skateboarding rinks when dry (Figure 27).
Vegetated features including rain gardens, bioswales, stormwater tree pits, infiltration planters, constructed wetlands, and other green infrastructure can be designed to infiltrate, evapotranspire, or temporarily store stormwater runoff during and after rainfall events.

To the right, examples of a bioswale and rain garden can be seen in Hawai‘i as well as in Washington (Figure 28).
Public utility systems, including electrical systems and mechanical equipment, should be protected from flood risk to avoid costly damage, safety risks, and loss of habitability and other critical building functions during a flood event. This should be among the highest priority resilience actions for government officials to reduce outages during flood events. In Honolulu, buildings in the Ward area raised their utilities and provided access via stairs (Figure 29).

Figure 29. City utilities elevated on concrete pad in Honolulu, Hawai‘i. Source: Google Maps.
Vaulted utilities can be beneficial for making maintenance easier by keeping water out and allowing greater accessibility. Utility lines in vaults can below-grade without being at risk to inundation from groundwater (Figure 30).
Water cisterns raised above the estimated water table can be used to temporarily store rainwater during heavy rainfall events.

One system type includes enclosed vaults (Figure 31) where water can be collected and temporarily detained within the system for a period of time during a heavy rainfall event (Rain Basin). Another system, Eco-Rain Tanks, consists of open “underground modular structures designed to accept and hold rain and runoff water for infiltration into the groundwater table, detention for controlled release, or for water reuse as a cistern” (Eco-Rain Tank Systems of America, Inc.) (Figure 32).

**Sizing Calculation**

To calculate the total detention volume for an area between one acre and 10 acres of existing impervious cover following the methodology specified in the City of Houston Design Manual, the appropriate equation is:

\[ V_t = [43,560 \times (0.50 \times A_{ii})] + (1815 \times A_{ei}) \]

- \( V_t \) = Total detention volume in Cubic Ft
- \( A_{ii} \) = Area of Impervious cover (acres)
- \( A_{ei} \) = Area of existing Impervious cover (acres) for which detention is not currently provided

Visit [rainbasin.parkusa.com](http://rainbasin.parkusa.com) for more information and design assistance.

**Below-grade Water Storage**

**Figure 31. RAINBASIN Underground Detention System**
Source: PARK/ “Rainbasin Underground Detention System”.

**Figure 32. Installation of below-grade water storage system. Source: Eco-Rain Tank Systems of America.**
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CHAPTER FIVE

SITE 1: WEST WAIKIKI
Low-Rise Residential Walk-Up Design Guidelines

The State of Hawai‘i has yet to define its own SLR-adjusted DFE standards. Water levels and proposed future design guidance for a low-rise residential walk-up building with at-grade spaces provided in Figure 33 show SLR-adjusted building DFEs for 2050 and 2100 using the best scientific data available.

Figure 33. Proposed Design Guidelines and Water Levels For Low-Rise Residential
Existing Buildings

Based on observation, each building is made up of three levels of residential units, constructed from concrete masonry units (CMU), and accessible via stairs located at either end of the building. Like other typical low-rise residential walk-ups, an on-site community laundry and storage room exist within the building on the ground floor. The current site of these buildings is located within FEMA Flood Zone AE with high risk of flooding and a BFE of six feet above LMSL indicated on the Flood Hazard Map for the area (FEMA 2021). Relative to current code and standards regarding FEMA-BFE and DFE levels, these buildings are not up to code. Originally built in 1950, the buildings have undergone limited renovations. Therefore, with future SLR and the need for higher DFEs, these buildings are vulnerable to SLR and may require significant retrofitting over time to continue current use. For example, the existing residential spaces most vulnerable to flooding are those located at ground-level/at-grade, as shown with the blue arrows (Figure 36).

Existing Streetscape

Ala Wai Boulevard is a major road that provides access in and out of Waikīkī and runs parallel to the Ala Wai Canal. Currently, the segment of Ala Wai Boulevard in West Waikīkī includes two lanes of two-way traffic as well as parallel parking along both sides of the street. As shown in Figure 35, the right side of the street is dedicated to a wider sidewalk buffer that incorporates shade trees and streetlights. The street is protected from the canal by a concrete wall, which delineates the boundary between the two. In contrast, the side of the street adjacent to the buildings has no trees or streetlights. Altogether, the current state of Ala Wai Boulevard provides limited space for pedestrians to use the sidewalks, prioritizing the space for both parked and traveling vehicles.
PRESENT CONDITIONS (2021)

Figure 36. Rendered image of Existing Site Conditions (2021)
Adaptation Strategies for Buildings w/ +2’ 0” SLR & 8” King Tide

In the following pages, two retrofit options are shown for 2050 that visualize how the low-rise residential buildings may adapt to a total of +2’ 0’’ SLR with a king tide of 8’.

By 2050, one option is to allow water to flow through the site by elevating buildings and walkways on open foundations (Figure 39). Because the existing residential spaces located at ground-level are most vulnerable to flooding, they should be repurposed only for parking, storage, or access. Current the NFIP regulations specify those types of uses for enclosed areas under elevated buildings (FEMA 2020). As a result, the removed residential spaces may be relocated to a new fourth floor, as shown outlined in orange, if the existing structure can be retrofitted to accommodate the additional load. This is similar to recommendations outlined in the Boston Resiliency Design Guidelines (City of Boston Planning and Development Agency 2019). Therefore, residential spaces would begin on the second floor above the SLR-DFE, as shown drawn above the dashed black line. Existing or new critical equipment should be raised on a platform or higher floor above the SLR-DFE. Elevated exterior stairs or ramps would provide pedestrian circulation between the street, open space, and building. In the reprogrammed first floor, wet floodproofing strategies below the SLR-DFE include installing flood vents at the perimeter walls of the building or stripping the existing structure down to its load-bearing components devoid of any non-structural walls and materials (FEMA 2020). Allowing the passage of water to flow in and out of the building equalizes hydrostatic forces of flood waters on exterior walls.

In the future, conveyance of stormwater runoff will be hampered by storm drain backflow and infiltration will be limited by higher groundwater tables. Therefore, on-site stormwater management strategies shown here include a new green roof to absorb and retain stormwater runoff from large rainfall events (Dunnett and Kingsbury 2008), and a water cistern to collect and store any additional runoff from the green roof. This non-potable can be reused later on-site for uses like watering plants.

Adaptation Strategies for Streetscape Without Stormwater Storage w/ +2’ 0” SLR & 8” King Tide

In the future, major roads and sidewalks will likely need to be elevated to remain accessible to emergency vehicles, public transportation, bicyclists, pedestrians, and limited single occupancy vehicles. The water table is estimated to be similar to the level of the ocean, and with 2 feet of sea level rise, the water table height is similar to the street height, which would cause an unstable road surface. With an 8’ king tide event, the street is estimated to flood (Figure 37).

The proposed design elevates Ala Wai Boulevard +2’ 0’’ above the existing street level (Figure 38). Currently, Honolulu design standards do not account for a rising water table. Research suggests that “...rising groundwater caused by sea level rise will intersect the unbound layers of coastal road infrastructure, weakening the pavement structure” (Jayne F. Knott et al. 2017). Typically, roads consist of three layers, including: 1) asphalt; 2) base; and 3) subgrade (Figure 37) (Knott et al. 2017). For this project, each typical layer is shown with an 8’ thickness. It is important to note that factors such as materiality, layer thickness, and subgrade quality affect the structure of the pavement (Knott et al. 2017). In this project, it was assumed that it would be acceptable for only the subgrade layer to become saturated. With +2’ 0’’ LMSL rise and an additional 8’ of water from a king tide event, the proposed new base and asphalt layer would remain dry, and the subgrade layer may become saturated over time. With more than 2’ 8’’ of sea level rise, the road will need to be raised again.

The proposal includes raised streets, less side-street parking, wider, sloped vegetated buffers and sidewalks for pedestrians, and vaulted utilities, consistent with the Honolulu Climate Adaptation Design Principles (CCH 2020).
MHHW (2021)
+2’ 0” SLR
+0’ 8” KING TIDE
APPROX. TOTAL: ↑ 2’ 8”

Figure 39. Rendered image of proposed retrofit site and buildings.
Adaptation Strategies for Buildings w/ +2’ 0” SLR & 8” King Tide

By 2050, a second option is to raise Ala Wai Boulevard higher than the previous proposal, +4’ 4” above the existing street level, (Figure 41) in order to incorporate below-grade water storage within the new fill. The below-grade modular hollow crate would be located below the road surface and above the water table, and temporarily detain stormwater runoff. For example, the Eco-Rain Tanks (Eco-Rain Tank Systems of America, n.d.) have been used in parking lots. As depicted in Figure 41, 12” of additional subgrade is added to create some dry space between the estimated water table and the bottom of the water storage crate. A minimum of 24” is shown from the top of the water storage crate to the top of the street. This is a typical detail shown for the Eco-Rain Tank system. Beyond 2’ 8” of SLR, the road will need to be raised again.

As shown previously, actions to vault and protect existing utilities and raise critical equipment are the same. Similarly, the number of lanes dedicated to traffic and street-side parking is minimized in favor of wider, sloped vegetated transition zones and wider sidewalks.

Stormwater runoff is directed to permeable, vegetated open spaces between buildings where it may infiltrate and be temporarily detained in the below-grade stormwater storage crate system.
Figure 42. Rendered image of proposed retrofit site and buildings.

MHHW (2021)
+2’ 0” SLR
+0’ 8” KING TIDE
APPROX. TOTAL: ↑ 2’ 8”
New Construction Strategies for Buildings w/ +6' 8" SLR & +10" King Tide

In addition to two retrofit options, a scenario of new construction to continue inhabiting this area with +6' 8" SLR and 10" of temporary flooding from a king tide event in 2100 was visualized (Figure 45). The existing buildings, which were originally built in 1950, would likely reach the end of their useful life by 2100, and a newly constructed dense, mixed-use development may better serve the site.

The future new construction may accommodate higher sea levels by elevating the site on fill or on an open foundation. For example, the building may be elevated on posts/columns, allowing water to flow freely underneath the buildings. Proposed actions include: elevate interior circulation via stairs and ramps, or elevate exterior circulation, and locate critical systems above the SLR-DFE in 2100.

Below-grade stormwater cisterns within the new fill of the proposed street. In comparison to the porous crate system (see Retrofit -- Option 2), the below-grade cisterns system should be sealed below ground to keep stormwater runoff separate from the rising groundwater table. For example, the ParkUSA RainBasin is an underground detention system with interconnected concrete vaults that are sized for a specific site.

Actions to vault and protect existing utilities and raise critical equipment are also shown. Again, traffic lanes and street-side parking at Ala Wai Boulevard are minimized in favor of wider, sloped vegetated transition zones and wider sidewalks.

Adaptation Strategies for the Streetscape w/ +6' 8" SLR & +10" King Tide

With 6’8” SLR and a 10” king tide, Ala Wai Boulevard must be raised +6’10” above the existing street level to avoid extensive flooding from SLR and throughout the entire site (Figure 43). As depicted in Figure 43, major roads such as Ala Wai Boulevard are raised while the surrounding area and minor streets are transformed into waterways where alternative modes of transportation such as water taxis may be used and encouraged. Stormwater is temporarily detained below-grade in enclosed cisterns located in the new fill of the proposed street. In comparison to the porous crate system (see Retrofit -- Option 2), the below-grade cisterns system should be sealed below ground to keep stormwater runoff separate from the rising groundwater table. For example, the ParkUSA RainBasin is an underground detention system with interconnected concrete vaults that are sized for a specific site.

Actions to vault and protect existing utilities and raise critical equipment are also shown. Again, traffic lanes and street-side parking at Ala Wai Boulevard are minimized in favor of wider, sloped vegetated transition zones and wider sidewalks.
MHHW (2021)
+6’ 8” SLR
+0’ 10” KING TIDE
APPROX. TOTAL: ↑ 7’ 6”

Figure 45. Rendered image of proposed new construction at site.
CHAPTER SIX

SITE 2: MAUKA WAIKIKĪ
The State of Hawai‘i has yet to define its own SLR-adjusted DFE standards. Water levels and proposed future design guidance for a high-rise residential tower with below-grade parking provided in Figure 46 show SLR-adjusted building DFEs for 2050 and 2100 using the best scientific data available.

Figure 46. Proposed Design Guidelines For High-Rise Residential
Existing Buildings

The typical high-rise residential building with below-grade parking (Figure 47) was built in 1967 and is located in a FEMA Flood Zone AO. The building is at high risk to flood from a river or stream and has a BFE two feet above LMSL indicated on the Flood Hazard Map (FEMA 2021). A visual comparison of the existing building shows it is likely in compliance with current code and standards for BFE and DFE in 2021. The building has below-grade parking located below the FEMA-BFE, however, this is acceptable based on the City and County Honolulu Revised Ordinances of Honolulu (ROH).

According to ROH “Chapter 21A: Flood Hazard Areas” Sec. 21A-1.8(c),

“... structures with fully enclosed areas below the lowest floor (excluding basements) that are usable solely for parking of vehicles, building access or storage, and which are subject to flooding, shall be designed to automatically equalize hydrostatic flood forces on exterior walls by allowing for the entry and exit of floodwaters” (CCH 2021).

In other words, below-grade spaces solely used for parking and/or storage are acceptable, if appropriately wet floodproofed. It is typical to find below-grade parking spaces along Ala Wai Boulevard with large, screened or unscreened openings.

As compared to the low rise building, this high-rise building was built more recently and has elevated occupied floors. Speculating that the building structure is sound, the design team explored potential flood adaptation strategies for 2050 and 2100 as the prototypical model for extending the useful life of a building.

Existing Streetscape

The second site located in the mauka area of Waikiki will be discussed in this chapter. Currently, the segment of Ala Wai Boulevard, adjacent to the high-rise residential building and Ala Wai Canal includes three lanes of one-way vehicular traffic, and sidewalks on either side of the street with minimal vegetated buffers. On the side of the street nearest to the canal there is a one shared bike lane and side-street parking. The major road circulates people and cars throughout mauka Waikiki.
Figure 47. Rendered section-perspective model of existing site conditions (2021)
Adaptation Strategies for Buildings w/ +2' 0" SLR & 8" King Tide

By 2050, with +2' 0" SLR plus 8" of additional water caused by a king tide event, the existing street and below-grade parking area would be flooded (Figure 48). Given the scale of these high-rise residential buildings, typically built in the late twentieth-century, they are more likely to be retrofitted to accommodate SLR rather than rebuilt. Related building adaptations to retrofit these buildings suggest filling the below-grade space to the nearest adjacent grade in 2050. This is consistent with the Boston Coastal Flood Resilience Design Guidelines, which recommends filling areas that are below the SLR-DFE to the nearest adjacent grade (City of Boston 2019). As a result, any critical systems related to the building which were previously located in the below-grade space should also be relocated above the SLR-DFE.

In addition, to better connect the existing building structure to the sidewalk below, a new pedestrian ramp is proposed. Due to a rising water table and the possibility of more frequent and heavy rainfall events, problems such as storm drain backflow and limited on-site drainage and infiltration may arise. Therefore, other best practices proposed for the building include new water cisterns to collect rainwater. These new water cisterns are shown above the new fill which was previously parking. Moreover, to detain and filter stormwater on-site various biofiltration strategies such as rain gardens, bioswales, and green roofs may also be incorporated in building design. As discussed in Chapter 1 (See Retrofit – Option 2), the possibility of incorporating a below-grade water crate system would detain stormwater runoff, shown within the new fill. Together these strategies are best applicable for the retrofit of a typical high-rise residential building with below-grade parking.

Adaptation Strategies for the Streetscape w/ +2' 0" SLR & 8" King Tide

By 2050, it is proposed that Ala Wai Boulevard is raised +2'1" above the existing street conditions, to avoid the risk of damage to the road from inundation of salt water. As mentioned previously, the proposed street elevation was determined by raising the depth of subgrade and asphalt material of the street above the estimated water table height (See Retrofit – Option 1). Actions to protect and vault existing utilities and raise critical equipment are also proposed. In addition, an extension of the pedestrian zone including a new proposed two-way bike lane is depicted. This was inspired by current plans from City and County Honolulu’s Waikiki Complete Streets plans to enhance recreational opportunities along Ala Wai Boulevard (CCH 2022). By 2050, side-street parking along Ala Wai Boulevard would be phased out, assuming that other modes of transportation are encouraged.

The rising ground water table and sea level limit stormwater infiltration and conveyance. Best practices, such as bioswales and rain gardens as a part of the streetscape, are proposed. The rain gardens may also act as vegetated buffers between both cars, bike, and pedestrian traffic. For example, the City of Portland encourages the design of “Green Streets” which are described as “… landscaped areas between the street and the sidewalk that use plants and soil to slow, filter, and clean stormwater running off streets and sidewalks” (City of Portland, n.d.) A case study relevant to this project was SW 12th Avenue Green Street at the Portland State University campus where the system manages approximately all runoff from the site, roughly equivalent to 180,000 gallons of runoff (City of Portland, n.d.). These practices emphasize the importance of adopting on-site water management to help ease the amount of runoff entering the main stormwater drain system, which experiences overflow during large rainfall events. Moreover, the use of new trees along both sides of the street help shade pedestrians and bicyclists using these pathways. Overall, by 2050 it is important to acknowledge how major roads like Ala Wai Boulevard will need to be raised and how other best practices such as rain gardens should also be designed in the future adaptation of this streetscape.
Figure 48. Rendered image of proposed retrofit site and buildings.

MHHW (2021)
+2’ 0” SLR
+0’ 8” KING TIDE
APPROX. TOTAL: ↑ 2’ 8”

RETROFIT (2050)

SLR-EEF for Retrofit/Ext. Coast
SLR-EEF +2’ 0” SLR +0’ KT
Adaptation Strategies for Buildings w/ +6’8” SLR & +10” King Tide

By 2100, with +6’8” SLR and an additional 10” of water caused by a king tide event, the following adaptations are proposed in order to ensure the continued useful life of this structure (Figure 49). First, the first floor of the building should be raised on fill, above the SLR-DFE to avoid the risk of flooding, and further built out to be repurposed as potential space meant for commercial/public activities. This new first floor would connect with the street level below through stairs and ramps to access this higher new first floor. This project was inspired by the City and County Honolulu vision of a “Resilient Streetscape Transition Zone.” As described in the City and County Honolulu “Climate Adaptation Design Principles for Urban Development,” “… this [Resilient Streetscape Transition] zone should mitigate the impact of the elevation change on the public realm by including amenities such as flood-resistant plantings, sidewalks, seating, trees, awnings, and other placemaking elements or design considerations” (2020). Therefore, the proposal to design for commercial/public activities at this new first floor is meant to encourage pedestrians to interact with the site. In addition, similar actions to relocate any critical building systems above the SLR-DFE to a higher floor and incorporate other best practices such as green roofs, below-grade water storage and water cisterns are shown. Overall, these strategies are applicable for the retrofit of a typical high-rise residential building with below-grade parking by 2100 to reduce risk from flooding due to sea level rise and enhance the way people use public and private space.

Adaptation Strategies for the Streetscape w/ +6’8” SLR & +10” King Tide

Through incremental change, Ala Wai Boulevard would need to be raised again, +4’11”, above the proposed 2050 street elevation, or 7’0” above the existing street elevation, to adapt to the increase in sea level rise and king tide levels projected for 2100. By then, it is projected there will be +6’8” SLR and 10” of temporary flooding caused by a king tide event that would extensively flood the area. Therefore, similar actions to protect and vault any existing utilities and raise critical equipment is necessary.

Similarly, the rain gardens and bioswales proposed in 2050 should be updated for 2100. It will be important to incorporate the design of bioswales and rain gardens as part of the streetscape to help ease the amount of runoff entering the stormwater main system. In addition, trees proposed in 2050 will have matured or new ones planted to avoid salt water inundation with the raised street to offer greater shade and protection for bikers and pedestrians using these paths. Until single-use vehicles are no longer relevant to the way roads are designed, the need to maintain Ala Wai Boulevard by raising it on fill and encouraging better water management strategies at the urban scale will be the standard course of action into the future.
RETOFIT (2100)

MHHW (2021)
+6’ 8” SLR
+0’ 10” KING TIDE
APPROX. TOTAL: 7’ 6”
CHAPTER SEVEN

GENERIC SITE: STRATEGY SUMMARY
SUMMARY OF STRATEGIES

ALA WAI CANAL

- Elevate Interior Circulation
- Elevate Critical Equipment
- Wet Floodproofing
- Elevate Critical Systems
- Floodable Open Space
- Elevate on Open Foundation
- Dry Floodproofing
- Elevate Exterior Circulation

- Repurpose Spaces Below DFE
- Building with Flood-resistant Materials
- Protect & Replace City Utilities
- Cistern/ Below Grade Water Storage
- Elevate on Fill
- Elevate Interior Circulation
- Ecological Water Treatment
- Raised Streetscape
- Resilient Streetscape
REFERENCES