Oahu Metropolitan Planning Organization
Transportation Asset Climate Change Risk Assessment Project

November 2011
Photo Credits from Cover

**Background:** Reef Runway, Runways, and Gates at Honolulu International Airport from Honolulu International Airport Master Plan Update, State of Hawaii Department of Transportation Airports Division, November 2010.

**Top Photo:** Hakimo Road Flooding, Waianae Coast by Sophie Flores

**Second Photo:** Shoreline of Campbell Industrial Park by SSFM International

**Third Photo:** Flooding of Mapunapuna by Pacific Business News, January 28, 2011

**Right Photo:** Sea Level Rise Model of Waikiki by Hawaii Coastal Geology Group, C. Fletcher and M. Barbee

**Bottom Photo:** Sand Island Access Road by flickr/Owen K. O'Neill/2009
This report was funded in part through grants from the Federal Highway Administration and Federal Transit Administration, U.S. Department of Transportation. The views and opinions of the agency expressed herein do not necessarily reflect those of the U.S. Department of Transportation.
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Section 1.0 Approach

The Oahu Metropolitan Planning Organization (OahuMPO) was selected by the Federal Highway Administration (FHWA) as one of five pilots nationwide to perform and evaluate a risk assessment of climate change on important transportation assets. The conceptual model shown below defines a method of integrating an inventory of assets with climate information and determining how vulnerable the asset is from two dimensions: the impact to the asset itself and, importantly, the socioeconomic consequences of that impact.

Figure 1: FHWA Climate Change Conceptual Model

While the bulk of this report addresses the outcomes of the vulnerability assessment of specific assets, it is important to place those findings in the context of the work that was done in three stages.

1. Understand climate change factors as they apply specifically to Oahu and, more generally, to island environments in the Pacific Ocean, over time. Given the climate data available and the evolving state of climate science understanding, the years 2050 and 2100 were defined as the time horizons for
consideration. A baseline of 1970-2000 was set as the measure against which future years’ impacts would be evaluated.

2. Conduct a two-day workshop to bring together both the climate science community and key planners and engineers from the City and County of Honolulu, State of Hawaii, Federal Highway Administration, and private industry to identify a set of transportation assets that may be particularly at risk due to climate change. The outcome of this workshop established a total of five assets that – if impacted adversely by climate change – have potentially high socioeconomic consequences to Oahu and the state of Hawaii.

3. Analyze the vulnerability of the selected assets based on the climate stressors that were identified during the workshop. This analysis was done by SSFM International, using a number of expert resources, as is discussed in detail in Section 2 of this report.

1.1 Workshop Preparation

Upon receiving the grant, OahuMPO determined that – to the fullest extent possible – it would work with the appropriate experts to identify and catalog both the climate change factors and transportation assets to be analyzed during the pilot. These represent the upper right and left quadrants of the conceptual model, respectively. The vulnerability assessment would be done independently by a qualified consultant. The components of that evaluation are found in the bottom half of Figure 1.

This triage-type approach was deemed both appropriate given the relatively compact geography of Oahu and the fact that the funding available for the effort relied heavily on the in-kind services provided by those who presented at and/or attended the workshop. Especially given the need for analyses of this type throughout the Pacific, where funding resources are scarce, OahuMPO determined this method would assist in the transfer of the protocols and technology to other jurisdictions both within the state of Hawaii and across the Pacific island nations, some of which are already experiencing far more severe climate change effects than those for which Oahu is preparing to adapt.

In preparing for the workshop, OahuMPO met with a number of nationally-recognized climate scientists, engineers, and planners from the University of Hawaii (UH) and the National Oceanographic and Atmospheric Administration (NOAA) that have specific focus on impacts to Hawaii and islands throughout the Pacific. These included representatives from:

University of Hawaii School of Ocean and Earth Science and Technology
- Charles “Chip” H. Fletcher III, Ph.D.
- Maxine Burkett, Ph.D., J.D.
- Zena Greci

National Oceanographic and Atmospheric Administration
- Dolan Eversole
- John A. Marra, Ph.D.
- Adam Stein, Ph.D.

University of Hawaii School of Civil Engineering
- C.S. Papacostas, Ph.D.
- Phillip Ooi, Ph.D.
- A. Ricardo Archilla, Ph.D.
- Ronald Riggs, Ph.D.
Federal Highway Administration
- Elizabeth E. Fischer, RLA, ASLA, APA, IAEM
- Jodi Chew
- Rebecca Lipes
- Butch Wlaschin, P.E.

Those meetings and discussions provided the baseline understanding of the climate change factors being experienced, in varying degrees, throughout the Pacific, and their impacts including:
- Sea level rise and shoreline erosion
- Changes in rainfall (increased drought followed by intense storm events and increased slope instability)
- Likelihood of increased hurricanes and typhoons and storm surge
- Air temperature and wind variables that affect cloud formation over islands

Concurrently and in consultation with its participating agencies, OahuMPO identified lead planners and engineers with specific knowledge of the various transportation assets that include Oahu’s highways, harbors, and airports. These planning and engineering resources represented the following agencies:
- Hawaii Department of Business, Economic Development and Tourism-Office of Planning
- Hawaii Department of Civil Defense
- Hawaii Department of Transportation
- Hawaii Local Technical Assistance Program
- Honolulu Department of Emergency Management
- Honolulu Department of Facility Maintenance
- Honolulu Department of Planning and Permitting
- Honolulu Department of Transportation Services
- National Renewable Energy Laboratory
- Pacific Disaster Center
- United States Department of Transportation – Federal Highway Administration
- University of Hawaii Department of Civil Engineering
- University of Hawaii Department of Urban and Regional Planning
- University of Hawaii William S. Richardson School of Law, Center for Island Climate Adaptation and Policy

In addition, representatives of private industry, including those from both energy (electric and petroleum providers) and transportation sectors participated as well as representatives of such environmental agencies as the Sierra Club. Three masters-level students studying at the East-West Center at the University of Hawaii participated from the island nations of Fiji, Solomon Islands, and Vanuatu. In addition, two Native Hawaiian cultural practitioners informed the discussion concerning the social and cultural impacts of climate change.

The workshop was assisted by representatives from ICF International, including Harrison Rue and Susan Asam, as well as by Marie Venner of Venner Consulting. ICF International was the consulting firm that developed the conceptual model for FHWA being studied by the five pilots.

Prior to the workshop, each participant received a short Pre-Workshop Preparation handout which functioned as a “think piece.” This piece was written by OahuMPO in cooperation with FHWA to address several of the climate change parameters that would be presented at the workshop and is included in this report as Appendix A. Participants were asked to consider the impacts of the climate changes on the transportation assets for which they have planning, engineering, or management responsibility.
1.2 Workshop

This section sets out the assumptions, discussion, and outcomes of the two-day workshop.

The workshop was attended by over 60 planning, engineering, and management professionals and students and was held at the East-West Center on March 8-9, 2011. The attendees are listed in Appendix B. The program was divided into three sections, and the agenda can be seen in Appendix C:

1.2.1 Climate Change Overview

The morning of the first day of the workshop was devoted to providing all participants with a baseline understanding of the state of climate science as it relates to Hawaii and other islands within the Pacific. This goal was achieved through a series of presentations that addressed specific climate change variables, the probability of their magnitude in the future, and provided examples of how these factors are already affecting Oahu and other Pacific island nations.

Speakers included:

- Charles “Chip” H. Fletcher, III, Ph.D., Associate Dean and Professor, UH School of Ocean and Earth Science and Technology (SOEST). Dr. Fletcher emphasized the science of global climate change, observed climate changes in Hawaii, and stressors likely to affect Oahu’s transportation infrastructure including:
  - Sea level rise
  - Inundation
  - Wave overtopping
  - Drainage
  - Slope stability
  - Thinking of climate change as a affects multiplier

- Kwok Fai Cheung, Ph.D., Professor, UH Department of Ocean and Resources Engineering. Dr. Cheung gave an interactive visual presentation of the model showing a category four hurricane and related tidal surge on the south shore of Oahu. The model had been prepared for a Federal Emergency Management Agency exercise done with a number of the military, civil defense, and emergency management agencies on Oahu. He gave a brief explanation of some of the impacts, e.g., flooding of Honolulu International Airport and time to reopen, isolation of Sand Island, loss of harbor infrastructure, loss of 80% of Oahu’s housing stock, loss of power generation and oil refining capabilities, and associated times to bring all back “on line.” His presentation touched on model assumptions and how they might change in light of higher sea-levels and/or if category four hurricanes were more common for Hawaii.

- Dolan Eversole, NOAA Coastal Storms Program Coordinator for the Pacific Region. Mr. Eversole gave a visual presentation on areas of Oahu that are currently experiencing effects of climate-related events on a regular basis, e.g., flooding in Mapunapuna and Campbell Industrial Park, effects of high waves on Kamehameha Highway on the north shore, rockfall at Makapuu and other slopes, as well as the impacts of historic events such as the flooding in 2006 as a result of 40 days of non-stop rain as well as of Hurricane Iniki in 1992.

- Butch Wlaschin, PE, Director, Office of Asset Management, Office of Infrastructure, FHWA. Mr. Wlaschin, looking at the “Big Picture” and taking the broadest view of engineering, sought to provide greater understanding how the environmentally variable drivers will affect design decisions now and in the future.

- Karl Kim, Ph.D., Professor, UH Department of Urban and Regional Development. Dr. Kim spoke about work currently being done to integrate climate science and urban planning, as well as challenges faced in terms of datasets and levels of uncertainty.

- Elizabeth E Fischer, RLA, ASLA, APA, IAEM, USDOT Emergency Coordinator, FHWA. Ms. Fischer spoke to climate change challenges and social impacts throughout Oceania and of what is already happening to the
Pacific islands of Fiji, Kiribati, and Samoa. She also gave an overview of the work being done by the Australia Council of State Governments, which places Australia about a decade ahead of the United States in planning for transportation infrastructure adaptation as a result of climate change.

Copies of these presentations may be found on the OahuMPO website at http://www.oahumpo.org/Climate%20Change%20Workshop%20Presentations.html

Brian Gibson, Executive Director of OahuMPO, was the Master of Ceremonies, and Randolph Sykes, Planning Coordinator of OahuMPO, provided introductory remarks. A complete list of attendees is given as Appendix B to this report.

OahuMPO acknowledges the significant assistance provided by the Hawaii Local Technical Assistance Program management and staff in coordinating the logistics of the conference, especially Juli Kobayashi and Gail Yamamoto.

1.2.2 Identification of Vulnerable Assets

The afternoon of the first day the participants broke into four groups and were given the task of identifying Oahu’s transportation assets that were vulnerable to the climate change factors discussed during the morning session. This resulted in lists that totaled 33 potentially vulnerable resources. These included harbor, highway, airport, bridge, and coastal infrastructure that could have catastrophic impacts on both the asset itself as well as on Oahu’s societal composition and economy. The facilitation team consolidated these lists for use the following day. Participants met in different groups on the morning of day two and each group had a copy of the consolidated listing of assets prepared from the prior day’s discussion. It was the goal of the morning exercise to determine, of the infrastructure identified, which was the more likely to be affected by climate change and have consequences that would be detrimental to both society and the economy. Each group needed to identify only five and provide a rationale for each of the assets it selected for the final list.

1.2.3 Prioritization of Assets

The afternoon of the second day was a plenary session where all of the participants were able to see the results of the syntheses by the morning groups. The final exercise was to take the four lists of high priority assets and develop a single list of not more than the five most important ones for future consideration during this pilot study.

Five transportation assets were selected for further analysis:

1. Honolulu Harbor Area;
2. Honolulu International Airport area, Honolulu International Airport, including Highways Division Oahu District Baseyard at 727 Kakoi Street, and 811 Middle Street Maintenance Facility and Middle Street Intermodal Transit Center;
3. Kalaeloa Airport, Kalaeloa Barbers Point Harbor, and Campbell Industrial Park;
4. Ala Moana Boulevard, Kalakaua Avenue, and McCully Street bridges to Waikiki; and
5. An example of a community where there was little system redundancy – Rt-93, Farrington Highway along the Waianae Coast.

Following the March workshop, OahuMPO engaged a consultant team that was responsible for determining the vulnerability of the five key transportation assets to the impacts of climate change, determining the consequence of that specified vulnerability, and assessing an integrated risk level.
1.3 Vulnerability Assessment

The balance of this report provides a vulnerability assessment of the five assets for each of the climate change variables. It is divided into seven sections.

1. Definitions of the transportation assets, explanations of the scientific assumptions of each climate change variable, and other definitions used in the workshops
2. Transportation Asset Group 1, Honolulu Harbor area
3. Transportation Asset Group 2, Honolulu Airport, including Highways Division Oahu District Baseyard at 727 Kakoi Street, and 811 Middle Street Maintenance Facility and Middle Street Intermodal Transit Center
4. Transportation Asset Group 3, Kalaeloa Airport, Kalaeloa Barbers Point Harbor, and Campbell Industrial Park
5. Transportation Asset Group 4, Ala Moana Boulevard, Kalakaua Avenue, and McCully Street bridges to Waikiki
6. Transportation Asset Group 5, Rt-93, Farrington Highway/Waianae Coast
7. Lessons learned and recommendations

Each transportation asset section provides information about the current condition of the asset, a geographic information system (GIS) map, photographs, socioeconomic data available for that asset area, and a report on how the risk assessment was achieved for that transportation asset. The final section will provide feedback on the process, data gaps, and other input that may be useful.

1.4 Consulting Project Team and Study Approach

The project team was inter-disciplinary and included practicing professionals in civil engineering, hydrology, landscape architecture, coastal engineering, geotechnology, climate change science, and transportation. Members of the team included:

- Project Management: Corey Matsuoka, P.E. (SSFM)
- Principal in Charge: Cheryl Soon, FAICP (SSFM)
- Planning: April Coloretti (SSFM)
- Civil Engineering: Robin Barnes (SSFM)
- GIS: Jared Chang (SSFM)
- Coastal Geologist: Chip Fletcher, Ph.D. (University of Hawaii, SOEST)
- Digital Cartographer: Matthew Barbee (Perspective Cartographic, LLC)
- Geotechnical Engineer: Robin Lim, P.E. (Geolabs, Inc.)
- Geotechnical Engineer: Steve Carr, R.G. (Geolabs, Inc.)
- Landscape Architect: Joel Kurokawa, ASLA (Ki Concepts, LLC)
- Landscape Architect: Tomo Murata, ASLA (Ki Concepts, LLC)

The inter-disciplinary team filled out the risk assessment matrix during three, day-long group work sessions. Team members prepared for each workshop by reading distributed materials and by offering information to the rest of the team on content relevant to their area of expertise. Data and articles were stored on a shared site hosted by SSFM. At the first workshop, which was held over a two-day period on August 15 and 16, 2011, the vulnerability and likelihood of outcomes were determined for each of the assets. A preliminary integrated risk assessment was assigned subject to further review. The second workshop was held eight weeks later on October 6, 2011. At that workshop, which was also attended by representatives of OahuMPO and FHWA, the team determined consequences to society and confirmed their assessment of the integrated risk for each of the transportation assets.
The workshops were led by Corey Matsuoka of SSFM, and discussion results were recorded on worksheets and notes taken by SSFM staff Cheryl Soon and April Coloretti. The Draft Report was distributed to each team member to add additional material and insights.

In order to help team members get accustomed to the model process, the consultant modified the FHWA Climate Change Concept Model as seen below in Figure 2.

**Figure 2: FHWA Climate Change Concept Model With Labels**

The FHWA Climate Change Concept Model Flowchart was boxed and labeled A through C.

A=Asset—The assets were numbered A1 through A5 for team workshop discussions.

B=Climate Change Variable—These climate change variables were lettered B

C=Steps for Risk Assessment—These were numbered C1 through C5.

The group work session proceeded in the following order for each transportation asset:

a. Presentations from subject matter experts for each transportation asset

b. Vulnerability assessment brain storming
   1. Likelihood of future climate changes
   2. Magnitude of future climate changes

c. Consequence of the impact on the transportation asset

d. Determination of the integrated risk
Several agencies and individuals were consulted in relation to each transportation asset to determine past experience of that facility with natural disasters and emergencies and to acquire local knowledge from facility operators.

Honolulu Harbor
- Engineering/Planning section of HDOT Harbors Division
- HDOT Highways Engineering staff for Sand Island Access Road
- City & County of Honolulu Environmental Services Department on Sand Island Wastewater Treatment Plant

Honolulu International Airport Area
- Oahu Transit Services, on TheBus, TheHandi-Van, and Intermodal Center
- HDOT Highways Division at 727 Kakoi Street Oahu Baseyard
- Engineering/Planning section of HDOT Airports Division on Honolulu International Airport

Kalaeloa Area
- Kapolei Property Development on Campbell Industrial Park
- City & County of Honolulu Environmental Services Department on H-POWER
- Engineering/Planning section of HDOT Harbors Division on Kalaeloa Harbor

Bridges into Waikiki
- HDOT Highways Engineering on conditions of Ala Moana Boulevard Bridge and Sand Island Access Road Bridge
- City & County of Honolulu Department of Design and Construction on Engineer’s Reports for Kalakaua Avenue Bridge and McCully Street Bridge

1.5 Definitions and Assumptions

1.5.1 Defining the Transportation Assets
Although the five transportation asset areas were chosen at the public agency workshop held in March 2011, many of them turned out to be an asset group or broad geographic area rather than a single asset. A considerable amount of effort was required to identify which critical facilities would be found at each asset area, as well as the land-side access leading to these assets. For example, within the Honolulu Harbor transportation asset, the project team listed each pier managed by HDOT Harbors Division as well as that pier’s function. The Honolulu Harbor “asset” also included land-side access to the harbor; however even with that, the important roads (Rt-92, Nimitz Highway; Rt-92, Ala Moana Boulevard; and Rt-64, Sand Island Access Road) needed to be referenced by cross streets to determine the important sub-sections of these long cross-town, urban roads. The project team developed a GIS map for each transportation asset, marking the beginning and end of the access roads as well as all fire stations, police stations, emergency shelters, hospitals, and clinics.

Once the five transportation asset areas were mapped, the consultant and OahuMPO met to define further each transportation asset in order to make the assessment manageable and meaningful to transportation decision-makers. If an asset had socio-economic value but was not a transportation asset, it was removed from the risk assessment. For example, the Waiau Power Plant was not studied as part of this risk assessment, but a general loss of electricity to a certain area was considered. In addition, the transportation asset named “System Redundancy Waianae-Farrington, Harbor, Kamehameha Highway, Kalanianaole Highway, Community Access” covered the majority of the island of Oahu. The scope of the project did not allow for the entire island to be studied, so the Rt-93, Farrington Highway along the Waianae Coast was selected as an asset representative of the “community access” category, which was defined as an area that lacked alternate routes, otherwise called system redundancy.
Transportation asset GIS maps were updated to show the five transportation asset areas, and each map is incorporated into this report as Appendix D.

1.5.2 Defining Climate Change

OahuMPO asked that the project team gather climate information with local or regional level information to include past changes and future climate projections. Historical climate and weather information was to be used to provide clues as to how assets may withstand future climate stressors. Projected climate information was to be used to estimate future climate conditions that transportation planners will want to consider.

The project team reviewed information from:
- University of Hawaii School of Ocean Earth and Science Technology (SOEST)
- US Geological Survey (USGS)
- National Oceanic and Atmospheric Administration (NOAA)
- Transportation Research Bureau (TRB)
- Federal Highway Administration (FHWA)
- International Council for Local Environmental Initiatives (ICLEI), Local Governments for Responsibility
- American Association of State Highway and Transportation Officials (AASHTO)
- Intergovernmental Panel on Climate Change (IPCC).

Each transportation asset lists the references used for assessment, and all references are included in the Resources section at the end of this report.

1.5.2.1 Assumptions

Table 1 lists the assumptions for the three climate change variables to be studied and sources for those assumptions. The variables of wind and temperature were added although they were not found to have major impacts on facilities.

The project team selected two planning horizons of 2050 and 2100 for this project, with a baseline of 1970-2000. The planning horizons were to give transportation planners time to adapt the transportation assets, while also showing the acceleration of climate change effects in the last half of the century, from 2050 to 2100. The baseline of 1970 to 2000 was selected so that the measurements would have an historical perspective and the ability to display trends. These definitions were all developed using available information from peer-reviewed literature, which is referenced at the bottom of Table 1 on the following page.

In order to perform this climate change risk assessment, the team assumed the worst case scenario with storm surge, where each asset would be in the upper right quadrant of a Category 4 hurricane and sustain the most damage.

The team assumed the best case scenario with sea level rise, which is three feet in 2100. The worst case scenario for sea level rise in 2100 for Hawaii is six feet. The team assumed the best case scenario for several reasons, one being that Hawaii does not experience the pooling or upwelling of water caused by El Niño because it is so close to the Equator. By contrast, other areas across the Pacific Ocean, such as Peru, experience the ocean at two feet higher during El Niño. This has led the State of California to choose the worst case scenario for sea level rise because it already has an additional two feet of sea level rise during the periods of El Niño. Should the ocean circulation patterns change drastically by the year 2100, Hawaii could experience a greater than three feet of sea level rise.
Table 1: Climate Change Variable Assumptions and Sources Materials

<table>
<thead>
<tr>
<th>Climate Change Variable</th>
<th>Baseline Definitions 1970-2000</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level Rise</td>
<td>0</td>
<td>+0.82 to 1.57 ft(^2) (Probable is approximately 1 foot)</td>
<td>+2.5 to 6.2 ft(^2) (Probable is approximately 3 feet)</td>
</tr>
<tr>
<td>Storm Surge</td>
<td># events</td>
<td>+15-30(^%) Increase in # of hurricanes</td>
<td>+30-60(^%)(^4)</td>
</tr>
<tr>
<td>Feet above Mean Sea Level (MSL)</td>
<td>Surge measure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall(^6)</td>
<td>Annual Mean: 25 inches(^5) Leeward Oahu annual average is 10 inches, and Central/Windward Oahu is 40 inches. Highest event: 154 inches(^7) Lowest Event (Drought)</td>
<td>-18% from 2000 (Even though less rainfall, rainfall events are likely to be more intense)</td>
<td>-20% from 2000 (Even though less rainfall, rainfall events are likely to be more intense)</td>
</tr>
<tr>
<td>Wind Velocity(^8)</td>
<td>Events will increase 0.25%/year • 0-38 mph (tropical storm) • 39-76 mph (tropical depression) • Hurricanes up to Cat 3</td>
<td>+12.5%</td>
<td>+25%</td>
</tr>
<tr>
<td>Air Temperature</td>
<td>Rising at 0.16(^\circ)F per decade(^9)</td>
<td>+0.8(^\circ)F (since 2000) Assumes no acceleration</td>
<td>+1.6(^\circ)F (since 2000) Assumes no acceleration</td>
</tr>
</tbody>
</table>

The project team determined that several of the terms, such as “storm surge” and “drought” needed further definition. OahuMPO provided some of the data sources to assist in the climate change variable definition process.

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7. Wiki Answers http://wiki.answers.com/Q/What_is_the_average_yearly_rainfall_in_Oahu#ixzz1TQxIjpj8 Link from OahuMPO.
1.5.2.2 Sea Level Rise

Reference from NOAA to define sea level rise:
Local mean sea level (LMSL) is defined as the height of the sea with respect to a land benchmark, averaged over a period of time (such as a month or a year) long enough that fluctuations caused by waves and tides are smoothed out. Sea level can rise by two different mechanisms with respect to climate change. The first is the expansion of the sea water as the oceans warm due to an increasing global temperature. The second mechanism is the melting of ice over land, which then adds water to the ocean.

http://sos.noaa.gov/datasets/Ocean/sea_level.html

An illustration of contributing factors to sea level rise is shown below in Figure 3. Figure 4 shows how sea level rise impacts the shoreline.

Figure 3: Factors Contributing to Sea Level Rise

![Factors Contributing to Sea Level Rise](Source: Global Energy Network Institute (GENI))

1. Glaciers: If the world's mountain glaciers and icecaps melt, sea levels will rise by an estimated 0.5 meters or approximately 1.5 feet
2. Thermal expansion: The expansion of warming oceans was the main factor contributing to sea level rise, in the 20th Century, and currently accounts for more than half of the observed rise in sea levels
3. Ice sheets: These vast reserves contain billions of tons of frozen water - if the largest of them (the East Antarctic ice sheet) melts, the global sea level will rise by an estimated 64 meters or approximately 210 feet

Figure 4: Sea Level Rise Impacts to the Shoreline

![Sea Level Rise Impacts to the Shoreline](Source: OahuMPO)
1.5.2.3 Storm Surge Definition

Storm surge\textsuperscript{10} is created by wind, waves, and low pressure.

There are three mechanisms that contribute to the storm surge:

1. The action of the winds piling up water (typically more than 85% of the surge).
2. Waves pushing water inland faster than it can drain off. This is called wave set-up. Wave set-up is typically 5 - 10% of the surge.
3. The low air pressure of a hurricane allowing a bulge of water under the eye that moves with the storm (typically 5 - 10% of the surge).

The storm surge depends greatly upon the size and intensity of a hurricane, the angle that it approaches the shore, how deep the water is close to shore (the slope of the seabed at the coastline), how fast the hurricane is moving, and the tide level at landfall.

**Figure 5: Storm Surge Depiction**

![Storm Surge Depiction](image)

*Depiction of a fifteen foot hurricane storm surge occurring at high tide of two feet above mean sea level, creating a seventeen foot storm tide. Note that there are 10-foot waves on top of the 17-foot storm tide, so the external high water mark (HWM) left on the outside of structures by this hurricane could be 27 feet or higher. Image credit: NOAA SLOSH Display Training Manual (PDF File).*

1.5.2.4 Hurricane Categories

Table 2 demonstrates the definition of hurricane categories 1-5 using the Saffir-Simpson Scale, which was developed in 1971. Based on available wind modeling, a Category 4 storm was used in this risk assessment analysis, which is defined as winds from 131-155 mph and storm surge of 13-18 feet.

\textsuperscript{10} Reference from http://www.wunderground.com/hurricane/surge.asp?MR=1
Table 2: Definition of Hurricane Categories

<table>
<thead>
<tr>
<th>Saffir-Simpson Hurricane Scale</th>
<th>Wind speed</th>
<th>Storm surge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>mph (km/h)</td>
<td>ft (m)</td>
</tr>
<tr>
<td>Five</td>
<td>≥ 156 (≥ 250)</td>
<td>&gt; 18 (&gt; 5.5)</td>
</tr>
<tr>
<td>Four</td>
<td>131–155 (210–249)</td>
<td>13–18 (4.0–5.5)</td>
</tr>
<tr>
<td>Three</td>
<td>111–130 (178–209)</td>
<td>9–12 (2.7–3.7)</td>
</tr>
<tr>
<td>Two</td>
<td>95–110 (154–177)</td>
<td>6–8 (1.8–2.4)</td>
</tr>
<tr>
<td>One</td>
<td>74–95 (119–153)</td>
<td>4–5 (1.2–1.5)</td>
</tr>
<tr>
<td>Additional classifications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tropical storm</td>
<td>39–73 (63–117)</td>
<td>0–3 (0–0.9)</td>
</tr>
<tr>
<td></td>
<td>(35–63)</td>
<td></td>
</tr>
<tr>
<td>Tropical depression</td>
<td>0–38 (0–62)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>(U=34)</td>
<td></td>
</tr>
</tbody>
</table>


1.5.2.5 Rainfall, Precipitation, and Drought Definitions

The rainfall by areas of Oahu is shown in Figure 6.

The definition of drought comes from NOAA National Climatic Data Center. Drought is a complex phenomenon which is difficult to monitor and define. Hurricanes, for example, have a definite beginning and end and can easily be seen as they develop and move. Drought, on the other hand, is the absence of water. It is a creeping phenomenon that slowly builds, impacting many sectors of the economy, and operating on many different time scales. As a result, the climatological community has defined four types of drought: 1) meteorological drought, 2) hydrological drought, 3) agricultural drought, and 4) socioeconomic drought. Meteorological drought happens when dry weather patterns dominate an area. Hydrological drought occurs when low water supply becomes evident, especially in streams, reservoirs, and groundwater levels, usually after many months of meteorological drought. Agricultural drought happens when crops become affected. And socioeconomic drought relates the supply and demand of various commodities to drought. Meteorological drought can begin and end rapidly, while hydrological drought takes much longer to develop and then recover. Many different indices have been developed over the decades to measure drought in these various sectors. The U.S. Drought Monitor depicts drought integrated across all time scales and differentiates between agricultural and hydrological impacts.

Figure 6: Annual Precipitation Map of Oahu in Inches

<table>
<thead>
<tr>
<th>Location</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waianae</td>
<td>8.6</td>
</tr>
<tr>
<td>Lualualei</td>
<td>19.9</td>
</tr>
<tr>
<td>Kunia Sub</td>
<td>11.5</td>
</tr>
<tr>
<td>Waipio</td>
<td>7.7</td>
</tr>
<tr>
<td>Mililani</td>
<td>15.2</td>
</tr>
<tr>
<td>Wheeler</td>
<td>17.5</td>
</tr>
<tr>
<td>Poamoho</td>
<td>18.7</td>
</tr>
<tr>
<td>Waialua</td>
<td>13.3</td>
</tr>
</tbody>
</table>

Source: National Disaster Center, managed by University of Hawaii and available at http://www.pdc.org/iweb/pdchome.html

The current prediction is for less rainfall on Oahu in the future and fewer rainfall events. However, when it does rain, it is more likely that the rainfall events will be far more intense than at present.

1.6 Definitions of Socioeconomic Measures and Consequences to Society

It was rather challenging to define and assess the consequences to society pertaining to the loss of each asset. This part of the exercise was qualitative in nature as the limited budget for the project did not permit a quantitative valuation. Socioeconomic data for the areas where assets were located were gathered from the U.S. Census in an attempt to identify the more vulnerable populations. These included total population, population under 18 or over 65, population where English is a second language, and poverty levels. Copies were provided to each team member.

It was not possible to conduct a full economic valuation of each asset. Therefore, in determining how valuable an asset might be, the following list was considered in the aggregate:

Ways to Value an Asset

- Level of use
- Use of asset for evacuation, civil defense activities, and emergency functions
- Degree of redundancy
- Cost to replace
- Economic loss
- Environmental impacts
- Cultural value
- Loss of life
- Recovery time needed
The team used a 3-tier low, moderate, high ranking system to classify vulnerability. These measurements were considered with respect to the three climate change factors that presented the highest vulnerability and had the greatest likelihood of occurrence. These categories were defined as follows:

- **Low Ranking:** Repair of asset needed, but can work around it
- **Moderate Ranking:** Asset is temporarily unusable and in need of repair
- **High Ranking:** Total catastrophic loss
Section 2.0 Risk Assessment of Honolulu Harbor

Asset Group Name: Honolulu Harbor

Facilities Named in this Asset:
- Honolulu Harbor Piers 1-53
- Rt-64, Sand Island Access Road starting at Rt-92, Nimitz Highway
- Rt-92, Nimitz Highway from Rt-64, Sand Island Access Road to Bishop Street (Pier 12)
- Rt-92, Ala Moana Boulevard from Bishop Street to Coral Street (Piers 1-11)

Figure 7: GIS Map of Honolulu Harbor Asset

2.1 Asset Description

Honolulu Harbor is the largest and busiest harbor in the state of Hawaii. Honolulu Harbor landside includes Piers 1-45 as well as piers 51A, 51B, 51C, 52, and 53 on Sand Island. The Harbor includes over 200 acres of container yard space, with container warehouse and storage sheds, as well as storage for cement, grain, and other bulk cargo.

Honolulu Harbor waterside consists of five major components:
1. Main Channel—also referred to as Fort Armstrong Channel, which is the Honolulu Harbor’s entry and exit point. Piers 1 & 2 and Fort Armstrong are adjacent to the Main Channel.
2. Main Harbor Basin—this area fronts the Aloha Tower Marketplace Complex on the landside and the Coast Guard dock on the Sand Island side. It includes Piers 5 through 27.
3. Kapalama Channel—this area fronts Piers 28-33 as well as parts of the Sand Island Container Terminal, and the Matson Terminal.

4. Kapalama Basin—this area includes Piers 34 to 45 as well as the remaining parts of the Sand Island Container Terminal at Piers 51A and 51B and the future Kapalama Terminal at Piers 42-45.

5. Kalihi Channel—this area is located west of Sand Island. The Sand Island Parkway drawbridge over this channel is permanently fixed in place, thus preventing ship passage.

There are many low-rise buildings and sheds located throughout the harbor. These are used by private shipping entities. The HDOT Harbors Division Office is located adjacent to Pier 12. Container operations are handled by gantry cranes, the largest being at Piers 51-53 for Matson. Interisland cargo is handled by the SaltChuk Resources Inc. subsidiary Young Brothers, Ltd. at Piers 39 and 40.

Figure 8: Gantry Crane

Access to the pier areas adjacent to the Main Channel of Honolulu Harbor is from State Rt-92 (Ala Moana Boulevard and Nimitz Highway). The Sand Island Container Terminal and Alexander and Baldwin’s Matson are accessible from State Rt-64, Sand Island Access Road.

For the purposes of this report, a risk assessment was not performed for portions of the harbor not used for cargo shipping, which includes the Aloha Tower asset and piers (Piers 5-11 and berths for visiting cruise ships); Pier 30, which is privately owned and operated for petroleum shipping and storage; and Piers 44-45, referred to as Snug Harbor, a University of Hawaii research facility.
### Table 3: Description of Piers in Honolulu Harbor

<table>
<thead>
<tr>
<th>Pier(s)</th>
<th>Berth Length in feet</th>
<th>Design Depth in feet</th>
<th>Principal Cargo/Pier Use</th>
<th>Access From</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,175</td>
<td>40</td>
<td>Fort Armstrong&lt;br&gt;Foreign containers&lt;br&gt;Neo-bulk cargo (lumber and building materials)</td>
<td>Ala Moana Boulevard (Rt-92)</td>
</tr>
<tr>
<td>2</td>
<td>1,850</td>
<td>35</td>
<td>Fort Armstrong&lt;br&gt;Cruise ship terminal&lt;br&gt;Foreign Trade Zone 9&lt;br&gt;Neo-bulk cargo</td>
<td>Ala Moana Boulevard (Rt-92)</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>12</td>
<td>Vehicle parking (adjacent to HDOT Harbors Office)</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>13</td>
<td>345</td>
<td>25</td>
<td>Tugboats, office space, vehicle parking&lt;br&gt;Tugboats, office space, vehicle parking</td>
<td></td>
</tr>
<tr>
<td>14/14END</td>
<td>280/150</td>
<td>21/35</td>
<td>Harbor fireboat&lt;br&gt;Tugboats, office space, vehicle parking</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>250</td>
<td>12-20</td>
<td>Commercial fishing boats&lt;br&gt;Commercial fishing boats&lt;br&gt;Pilot boats, loading dock, storage and repair sheds</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>930</td>
<td>18</td>
<td>Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo and Roll on/Roll Off (RO/RO)</td>
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<tr>
<td>17</td>
<td>971</td>
<td>20</td>
<td>Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo</td>
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<tr>
<td>18</td>
<td>214</td>
<td>20</td>
<td>Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>530</td>
<td>32-34</td>
<td>Ferry terminal, tugboats, cruise ships, barges, cargo, shed&lt;br&gt;Tugboats, barges, and general cargo</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>20</td>
<td>480</td>
<td>34</td>
<td>Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo</td>
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<tr>
<td>21</td>
<td>494</td>
<td>35</td>
<td>Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo</td>
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<tr>
<td>22</td>
<td>446</td>
<td>33</td>
<td>Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo</td>
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<tr>
<td>23</td>
<td>500</td>
<td>31</td>
<td>Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>558</td>
<td>25</td>
<td>Barges, grain ship and grain storage&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo</td>
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<tr>
<td>25</td>
<td>365</td>
<td>30</td>
<td>Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo</td>
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<tr>
<td>26</td>
<td>685</td>
<td>30</td>
<td>Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>500</td>
<td>30</td>
<td>Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo&lt;br&gt;Tugboats, barges, and general cargo</td>
<td></td>
</tr>
<tr>
<td>27 DOG LEG</td>
<td>225</td>
<td>20</td>
<td>Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo</td>
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</tr>
<tr>
<td>28 END</td>
<td>150</td>
<td>30</td>
<td>Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo</td>
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<td>29</td>
<td>722</td>
<td>35</td>
<td>Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>801</td>
<td>35</td>
<td>Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo&lt;br&gt;Tugboats, barges and general cargo</td>
<td></td>
</tr>
<tr>
<td>30 Privately Owned</td>
<td></td>
<td></td>
<td>Privately Owned Petroleum shipping and storage</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>31</td>
<td>400</td>
<td>35</td>
<td>General cargo and storage sheds&lt;br&gt;General cargo and storage sheds&lt;br&gt;Bunkering (fueling), pipelines, general cargo, and RO/RO</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>31A</td>
<td>375</td>
<td>35</td>
<td>General cargo and storage sheds&lt;br&gt;Bunkering (fueling), pipelines, general cargo, and RO/RO</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>32</td>
<td>400</td>
<td>35</td>
<td>General cargo, dry bulk cargo, and RO/RO&lt;br&gt;General cargo, dry bulk cargo, and RO/RO</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>33</td>
<td>325</td>
<td>35</td>
<td>Bunkering (fueling), pipelines, and general cargo&lt;br&gt;Bunkering (fueling), pipelines, and general cargo&lt;br&gt;Bunkering (fueling), pipelines, and general cargo&lt;br&gt;Bunkering (fueling), pipelines, and general cargo&lt;br&gt;Bunkering (fueling), pipelines, and general cargo</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>34</td>
<td>545</td>
<td>35</td>
<td>Bunkering (fueling), pipelines, and general cargo&lt;br&gt;Bunkering (fueling), pipelines, and general cargo&lt;br&gt;Bunkering (fueling), pipelines, and general cargo&lt;br&gt;Bunkering (fueling), pipelines, and general cargo&lt;br&gt;Bunkering (fueling), pipelines, and general cargo</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>35</td>
<td>705</td>
<td>35</td>
<td>Oil spill response vessel and general cargo&lt;br&gt;Oil spill response vessel and general cargo&lt;br&gt;Oil spill response vessel and general cargo&lt;br&gt;Oil spill response vessel and general cargo&lt;br&gt;Oil spill response vessel and general cargo</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>36-38</td>
<td>62-587</td>
<td>10-35</td>
<td>Commercial fishing village&lt;br&gt;Commercial fishing boats and fish auction&lt;br&gt;Commercial fishing boats and propane barge</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>39-40</td>
<td>100-513</td>
<td>30-36</td>
<td>Young Brothers (interisland cargo)&lt;br&gt;Young Brothers (interisland cargo)&lt;br&gt;Young Brothers (interisland cargo)&lt;br&gt;Young Brothers (interisland cargo)&lt;br&gt;Young Brothers (interisland cargo)</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>41</td>
<td>900</td>
<td>22-34</td>
<td>Dry-docks and ship repair facility&lt;br&gt;Container freight station&lt;br&gt;Container freight station&lt;br&gt;Container freight station&lt;br&gt;Container freight station</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>42</td>
<td>210 (East) 300 (West)</td>
<td>22-34</td>
<td>Dry-docks and ship repair facility&lt;br&gt;Container freight station&lt;br&gt;Container freight station&lt;br&gt;Container freight station&lt;br&gt;Container freight station</td>
<td>Nimitz Highway (Rt-92)</td>
</tr>
<tr>
<td>51-53</td>
<td>556-1,160</td>
<td>37-40</td>
<td>Matson on Sand Island&lt;br&gt;Domestic containers, autos, RO/RO, petroleum&lt;br&gt;Matson on Sand Island&lt;br&gt;Domestic containers, autos, RO/RO, petroleum&lt;br&gt;Matson on Sand Island&lt;br&gt;Domestic containers, autos, RO/RO, petroleum</td>
<td>Sand Island Access Road (Rt-64)</td>
</tr>
</tbody>
</table>

2.2 Importance of the Asset Group to Society

<table>
<thead>
<tr>
<th>Societal Value of Asset</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of Use</td>
<td>HIGH</td>
</tr>
<tr>
<td>Degree of Redundancy</td>
<td>LOW</td>
</tr>
<tr>
<td>Cost to Replace</td>
<td>HIGH</td>
</tr>
<tr>
<td>Economic Loss</td>
<td>HIGH</td>
</tr>
<tr>
<td>Environmental Impacts</td>
<td>LOW-MODERATE</td>
</tr>
<tr>
<td>Cultural Value</td>
<td>LOW</td>
</tr>
<tr>
<td>Loss of Life</td>
<td>LOW</td>
</tr>
<tr>
<td>Recovery Time Needed</td>
<td>HIGH</td>
</tr>
</tbody>
</table>

Approximately 90% of Hawaii’s goods are imported into the state. Of that amount, 98% comes through the State commercial harbors system, and this includes all goods destined for neighbor islands which must arrive on Oahu first before being shipped off to them. Honolulu Harbor is the largest and busiest harbor in the state, and access to and from it is critical. Large container ships and tankers arrive and are loaded and discharged around the clock. The harbor handles over 8 million short tons of cargo annually. According to HDOT’s Harbors Division, cargo arriving in the state is expected to grow at a rate of 3-4% per year. Interisland barge departures from Honolulu Harbor have also increased 33% since 2001 and are predicted to grow.

Honolulu Harbor is home to one cruise line, Norwegian Cruise Line’s Pride of America, and is visited by other cruise lines year round. In 2010, 23 cruise ships arrived in Hawaii with 101,239 visitors. Honolulu Harbor receives all goods except bulk petroleum, bulk coal, bulk cement, and bulk construction materials. These goods are offloaded at Kalaeloa Harbor, which is discussed in Section 4.

The Honolulu Harbor area has very few residents, so the team did not consider evacuation measures in the socioeconomic evaluation of this asset. The team did note that Iwilei, which is adjacent to Honolulu Harbor but not part of the study area, contains two homeless shelters for families and men. Chinatown, which is also not part of this evaluation but adjacent to Honolulu Harbor also includes several social service agencies in addition to several temples and a variety of residents. Much of this information is included in the State of Hawaii Multi-Hazard Hazard Mitigation Plan 2010 Update from the Hawaii State Civil Defense. The City & County of Honolulu Department of Emergency Management is currently developing an evacuation plan for the island of Oahu.

The main links between much of the cargo activity and the general population are along Rt-64, Sand Island Access Road, Sand Island Parkway Bridge, and Rt-92, Nimitz Highway. As discussed in the preceding sections, the abutment footings on the Sand Island Parkway Bridge are just on the edge of modeled hurricane storm surge. While Sand Island Access Road may not completely flood, there are portions of Rt-92, Nimitz Highway that could become overwhelmed by storm surge. There is some redundancy built into the highway transportation system so that different routes could be taken in order to bypass these portions of Nimitz Highway if it became inaccessible.

Based on discussions with the City & County of Honolulu Department of Environmental Services, it was determined that there would not be any socioeconomic impacts to consider from the Sand Island Wastewater Treatment Plant (Sand Island WWTP). In the history of known storms, the Sand Island WWTP has never shut down. However, a Category 4 hurricane has never made a direct hit in an area that would have impacted the facility.
Of greater concern is the effect of storm surge on the piers and storage areas, as well as containers that could fall into Honolulu Harbor, blocking ships from accessing the piers themselves.

**Figure 10: Cargo Containers after Tsunami in Sendai, Japan**

![Cargo Containers after Tsunami in Sendai, Japan](image)

*Source: Kyodo News/AP www.spokesman.com, March 11, 2011*

The team recognized that in the event of a hurricane or severe storm, most vessels using the harbor would have enough notice to be directed out to sea until the storm event passed. In terms of the effects of sea level rise, the team acknowledged that there is time to prepare and adapt the harbor facilities, and enough time so that the adaptation’s cost and logistics can be spread out over several decades.

The largest disruption would be to the supply chain, and it would be significant even if temporary. This includes food, goods, materials, and even some fuel. The team did not have the scope to consider all of the environmental effects of climate change, but the team did want to note that the fuel storage tanks right along Honolulu Harbor could create a severe secondary environmental impact if they should rupture or leak and should be considered for any hazard mitigation.
2.3 Risk Assessment for Honolulu Harbor

A. Sea Level Rise: (see maps in Appendix D)

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Low Vulnerability, Low Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>Moderate Vulnerability, Moderate Structural Impact</td>
</tr>
</tbody>
</table>

**Reasons & Discussion**

The mean tidal range at Honolulu Harbor is currently approximately 1.9 feet, with the extreme range at approximately 2.3 feet under spring tide conditions. The highest tide on record is +3.1 feet Mean Sea Level (MSL), and the lowest tide on record is -1.15 feet (MSL). The tidal current floods west and ebbs east along the coast between Makapuu Point and Honolulu Harbor.11

By 2050 with approximately one foot of expected sea level rise, the assessment concludes that there may be minimal impact to the Honolulu Harbor assets. The majority of the sea level rise impact is expected to be along the south facing ocean-side shore of Sand Island, and this may not impact harbor operations. Sand Island is made from reclaimed land and could be prone to erosion in the coastal sections that are not hardened.

By 2100 with approximately three feet of predicted sea level rise, there will be significant loss of land on the south-facing shore of Sand Island as well as on the seaward side of Sand Island Access Road (SR-64), nearest to the Keehi Boat Harbor. The south-facing shore is currently a vegetated open space. Loss of vegetative buffer zone may accelerate the erosion process and expose the Sand Island Wastewater Treatment Plant (WWTP) to tidal inundation. Three feet of sea level rise may flood the area between Snug Harbor (Piers 44/45) and Pier 41. The banks of Nuuanu Stream may experience erosion.

Mean Higher High Water (MHHW) is the average of elevations of higher high waters over the national tidal datum epoch of 1983 to 2001. For the sea level rise modeling at MHHW by 2100, sea level may rise above the banks of all piers from Pier 42 and all the way to Piers 1 and 2. When the sea level rises higher relative to the pier, it could severely impact loading or offloading vessels.

Currently, HDOT Harbors Division is planning to construct a new 70-acre Kapalama Container Terminal yard, located at the former Kapalama Military Reservation behind Snug Harbor. As discussed above, this area may experience sea level rise and inundation, and design of the facility should take this into account.

B. Storm Surge: (see map in Appendix D)

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>High Vulnerability, High Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>High Vulnerability, High Structural Impact</td>
</tr>
</tbody>
</table>

**Reasons & Discussion**

The team evaluated the Honolulu Harbor in six sub-areas to see how storm surge modeling affected different areas of the asset. The six areas evaluated were: Sand Island, Young Brothers Piers 39/40, Piers 1/2 Fort Armstrong, the Sand Island WWTP, the new Kapalama Container Terminal, and the HDOT Harbors Division Offices on Rt-92, Nimitz Highway adjacent to Pier 12.

---

The storm surge modeling is based on a Category 4 storm center passing within approximately 100 miles to the west of Honolulu Harbor, putting this transportation asset in the eastern hemisphere or northeastern quadrant of the storm. This is the strongest part of the hurricane and most vulnerable to storm surge. The storm surge model showed a sea level surge between three and ten feet at present day Mean Sea Level elevation.

The model predicts that the most severe storm surge impact may be at Young Brothers Piers 39/40, due to its low-lying elevation, as well as being adjacent to Nuuanu Stream, which could amplify the surge inundation. Access to Piers 1 & 2 from Rt-92, Ala Moana Boulevard may be closed, and the planned Kapalama Container Terminal may be highly vulnerable to storm surge.

The team noted that Iwilei, which is adjacent to Honolulu Harbor, may have considerable flooding, making access difficult to Honolulu Harbor from Rt-92, Nimitz Highway. The Sand Island Parkway Bridge on Rt-64 may be inaccessible from Rt-92, Nimitz Highway, partially due to the amplification of storm surge near Kapalama Stream. Sand Island may experience some shoreline erosion due to storm surge, but the vegetation on the south shore could work as a natural buffer zone against storm surge.

The Sand Island Parkway Bridge over Kalihi Channel is actually two bridges connected together, one made from concrete and the other a “Bascule Bridge.” The Bascule Bridge is the original metal two-lane drawbridge that was permanently sealed in the late 1980s when HDOT built a new concrete bridge alongside it to create four lanes that would accommodate the growing traffic. The latest bridge inspection report (2006) shows minor spall and minor edge nicks, with recommendations to remove debris from the joints and restripe edge lines. The bridge is deemed to be structurally sound, even with the heavy loads of several thousand trucks passing over it each day. When discussing storm surge, the team identified that the abutment footings of the Sand Island Parkway Bridge are just at the edge of the modeled hurricane storm surge inundation.

It is important to note that the storm surge model is based on present day sea level, so these impacts may be further amplified with a sea level rise of one foot in 2050 and three feet in 2100.

C. Wind

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Low Vulnerability, Low Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>Moderate Vulnerability, Moderate Structural Impact</td>
</tr>
</tbody>
</table>

Reasons & Discussion

The team identified the potential risks of increased wind velocity on gantry cranes at Sand Island. The Port of New Orleans gantry cranes are designed to withstand hurricane force winds at 120 mph, which is a Category 3 hurricane. In the event of forecasted heavy winds, they utilize hurricane tie downs on each of the four corners of the crane. These are heavy turnbuckles connecting the cranes to specific heavy tie down locations in the dock. With all of the hurricanes sustained by New Orleans, they have not had any issues with structural soundness of their gantry cranes.

The team contacted Matson Navigation Company, which operates 7 gantry cranes at Honolulu Harbor. All Mastson cranes are designed and outfitted with hardware to resist Uniform International Building Code wind loads. This includes designated stow locations and stow pins with corresponding dock sockets. All 7 gantry cranes also include rail-clamp or wedge-type wheel brakes in their design.

The team selected a low integrated risk assessment for 2050, but increased the integrated risk assessment to moderate for 2100 because wind velocity is predicted to increase up to 25% by 2100. This predicted increase in
wind velocity coupled with the predicted increase in frequency between 30-60% by 2100 gave this asset a moderate ranking for the end of the century in the climate change category of wind.

D. High Intensity Rainfall

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
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</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>Moderate Vulnerability, Moderate Structural Impact</td>
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</table>

*Reasons & Discussion*

Precipitation is predicted to decrease 18% by 2050 from 2000 precipitation levels. Precipitation is predicted to decrease 20% from 2000 precipitation levels by 2100. The predicted impact of climate change on Oahu is that it will receive less rain overall and it will rain less frequently, but when it does rain, it is more likely to be a high-intensity, heavy rainfall event. The team considered problems in this area due to flooding of Kapalama and Nuuanu streams.

The team determined that, even with ponding water on roadways and breaching of the banks of the two stream channels, there were enough alternate routes for harbor access due to their roadway elevation. Sand Island Parkway Bridge on Rt-64 may not flood to the extent that it becomes impassable in heavy rains.

Currently, the HDOT's Highways Division Oahu District Office reports that it does not receive trouble calls for flooding along Rt-92, Nimitz Highway and Ala Moana Boulevard. With sea level rise, ponding water may increase during heavy rains since these access roads may be close to the groundwater level.

For these reasons, the team ranked this asset as low vulnerability and low impact in 2050, but increased both vulnerability and impact to moderate in 2100 due to the combined effects with predicted sea level rise.

E. Air Temperature

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<tr>
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<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>Low Vulnerability, Low Structural Impact</td>
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</table>

*Reasons & Discussion*

While the air temperature is rising at 0.16°F per decade, with an increase of 1.6°F by 2100 over 2000 levels, the air temperature was not deemed to have any significant effect on this transportation asset.

2.4 Integrated Risk Assessment

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
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<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>HIGH</td>
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</table>
Reasons & Discussion

Of the five climate change variables, storm surge was the only variable having a high vulnerability and high impact for both 2050 and 2100. Climate change variables including high intensity rainfall, sea level rise, and wind were ranked by the teams as having a moderate impact and vulnerability to this transportation asset.

The storm surge vulnerability and impact at present day is already high, and the predicted sea level rise of one foot in 2050 and three feet in 2100 may only amplify the vulnerability and impact.

The socioeconomic value for this transportation asset is high due to the fact that approximately 90% of the goods shipped into Hawaii must arrive by sea, most of which is currently offloaded at Honolulu Harbor.

In addition, HDOT Harbors Division is planning to build a 70-acre container terminal yard at the former Kapalama Military Reservation, and this new asset may be affected by both sea level rise and storm surge.

For these reasons, the team selected a high integrated risk for vulnerability, impact, and consequences to society for Honolulu Harbor for both 2050 and 2100.

2.5 Data Sources


Department of Business, Economic Development & Tourism. 2010 Data Book.


Matson Navigation Company. Paul Johnescu. Vice President, Matson Navigation Company. PJohnescu@matson.com


Sea Level Modeling by University of Hawaii Coastal Geology Group, C. Fletcher and M. Barbee. 2011.
Section 3.0 Risk Assessment of Honolulu International Airport

Asset Group: Honolulu International Airport

Facilities Named in this Asset
- Honolulu International Airport
- Joint Base Pearl Harbor-Hickam Runway
- Airport access routes along Lagoon Drive and Rt-92, Nimitz Highway
- HDOT Highways Division Oahu District Baseyard at 727 Kakoi Street
- TheBus and TheHandi-Van facilities at 811 Middle Street and Middle Street Intermodal Center

Figure 11: GIS Map of Honolulu International Airport Asset
3.1 Description of the Asset

Honolulu International Airport is the largest airport in the state of Hawaii comprising over 3,500 acres of land. The tower and runways are shared use with Joint Base Pearl Harbor-Hickam. Honolulu International Airport currently accommodates approximately 60% of the state’s air passengers. The Honolulu International Airport is approximately 13 feet above sea level, and access to it is from Lagoon Drive, Rt-92 (Nimitz Highway), and the Interstate H-1 Freeway.

North of Rt-92, Nimitz Highway from the Airport is the HDOT Highways Division Oahu District Baseyard, which is located at 727 Kakoi Street in Mapunapuna. Kakoi Street is accessed from Rt-92, Nimitz Highway. This baseyard holds approximately 280 vehicles ranging in size from small utility pickups to large operation equipment. The baseyard has two gas pumps, two underground storage tanks, and one pit for repairs by the motor pool. Waste oil is kept underground, and utilities are also underground. This baseyard facility is adjacent to Moanalua Stream, with a ground elevation of approximately eight feet above sea level.

TheBus Facility is located at 811 Middle Street. This facility contains TheHandi-Van maintenance and administration buildings, Oahu Transportation Services’ administration and maintenance buildings, a shop for vehicle parts, and a garage to repair vehicles. It is one of two bus maintenance facilities, the other being at Pearl City/Manana. Oahu Transit Services operates both TheBus and TheHandi-Van for the City & County of Honolulu. The system has 295 fixed route buses, 150 TheHandi-Van vehicles for paratransit, and 450 surface vehicles. These facilities are located along Kalihi Stream.
The Middle Street Intermodal Facility just opened in October 2011 for buses and parking. It will connect with the Honolulu High-Capacity Transit Corridor Project, popularly known as “The Rail.” It is located at the intersection of Dillingham Boulevard and Middle Street.

Both the Honolulu International Airport and the Mapunapuna area were built on filled lands. Prior to the development of the airport, the area consisted of mixed marshland with shallow lagoons and emerged lowlands containing unconsolidated marine sediments and hardened coral reefs. Both areas also contained several ancient Hawaiian fishponds, which still existed as late as 1927 as shown in Figure 13 below. According to the non-profit group Kai Makana’s curriculum for Mokauea Island, “Ha’awina for Mokauea Island,” in 1927 there were 13 fishponds in this area encompassing 857 acres. Kaloalaoa Pond and, earlier, Kaihikapu Pond were located where Honolulu International Airport and Joint Base Pearl Harbor-Hickam currently have runways.

Figure 13: 1927 Map of Honolulu International Airport Fishponds

The airport area was filled in with coral from the surrounding reefs, and Mapunapuna was filled in around the same time. Figure 14 shows Mapunapuna Pond where Mapunapuna industrial area is currently located. It is probable that this pond was a freshwater spring due to the geologic setting and the Moanalua Stream drainage system.

Both of these figures are important to this report because they show the original geography and geology of this transportation asset, including how close to sea level the transportation assets in this asset group are, and how the land was created in the last century from fill and coral.

Access to the airport is provided by Lagoon Drive and Rt-92, Nimitz Highway all at ground level, as well as from the Interstate H-1 Freeway viaduct, which runs above Rt-92, Nimitz Highway.

3.2 Importance of the Asset Group to Society

A. Honolulu International Airport

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<tbody>
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<td>Societal Value of Asset</td>
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<tr>
<td>Level of Use</td>
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<td>Degree of Redundancy</td>
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<td>Economic Loss</td>
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<td>Environmental Impacts</td>
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<td>Cultural Value</td>
<td>LOW</td>
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<tr>
<td>Loss of Life</td>
<td>LOW</td>
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<tr>
<td>Recovery Time Needed</td>
<td>HIGH</td>
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</tbody>
</table>
According to the HDOT Hawaii Aviation Website, the Honolulu International Airport was first constructed in 1927 with 885 acres at Keehi Lagoon. Today it handles nearly 19 million passengers annually from all over the world, as well as approximately 350,000 cargo tons a year (excluding mail). Honolulu International Airport is the dominant air hub and it serves connections to overseas destinations as well as to other state airports by a large and ever-changing mix of airlines. It is the 25th busiest airport in the nation. At this time, 24 airlines offer passenger and cargo service to, from, and within Hawaii. Four airlines now offer interisland service: Hawaiian Air, Island Air Hawaii, go! Mokulele, and Pacific Wings. With these statistics, the team ranked this transportation asset a high value.

The Reef Runway is the longest runway in the state at 12,360 feet. The Honolulu International Airport shares operations with Joint Base Pearl Harbor-Hickam. The airport’s backup, in case of emergency, is Kalaeloa Airport.

The team assumed that in the event of severe storm or hurricane, the airport’s downtime would be similar to that of Sendai Airport in Japan following the March 11, 2011, Tohoku earthquake and tsunami. In that instance, the airport’s tarmac, taxiways and runway were completely submerged, while electrical equipment and transformers were rendered inoperable.

![Figure 15: Sendai Airport after March 11, 2011 Tsunami](Photo: Reuters/KYODO)

Military engineers opened the Sendai Airport by March 17 for tsunami response flights. Limited commercial traffic began on April 13, approximately one month after the twin disasters. After suffering from extreme losses brought on by the earthquake, tsunami, and nuclear reactor meltdown, it took only six days to clear the airport for emergency response flights. Using Sendai Airport as a point of reference, the team assumed one-to-two weeks of downtime for commercial flights, and one-to-three days of downtime for emergency response.

According to the HDOT Airports Division, Kalaeloa Airport is the backup to Honolulu International Airport. One item that may need further study is how long it would take Kalaeloa Airport to get up to the functionality of taking on commercial flights that have been rerouted from Honolulu International Airport. It is important to note that in the event of a storm disaster, Kalaeloa Airport may also be somewhat susceptible to storm damage from the same disaster and could require some level of repair in order to function in a backup capacity.
Another socioeconomic issue to consider is the affect on businesses should the state’s largest airport shut down. After the nation’s airports were shut down for three days after September 11, 2001, it took about one week to get all tourists out of the state. At that time, the entire nation’s airports were struggling to keep up with the disruption from three days of lost travel as well as the public’s emotional desire to get back home as soon as possible. While it may not take an entire week to evacuate all tourists off island in the event of the airport’s shut down, it would take several days due to the fact that no other airport in the state can handle the volume that passes through Honolulu.

Aside from the immediate effects of an airport shutdown, there are many long term effects to consider. The team discussed the effect of Hurricane Iniki on Kauai’s economy in 1992. While the airport was operational for emergency operations just one day later, and 7,000 people were flown off the island for the two days following the hurricane, the airport did not resume regular passenger service for several weeks. It took eight years for Kauai’s economy to reach pre-Iniki levels, and today nearly 20 years later, it has still not recovered in terms of its population and labor force. Immediately after Iniki, Kauai’s unemployment went from 7% up to 19.1%. The University of Hawaii Economic Research Organization (UHERO) states that the island of Kauai permanently lost about 10% of its population and 12% of its income.

Because Oahu’s population, tourism, and employment bases are orders of magnitude higher than Kauai’s, the team believes that damage to the Honolulu International Airport asset could have long-term, devastating social and economic consequences not just to the island, but the state.

The team considered an aggregate list of considerations when placing a socioeconomic value of the asset, including but not limited to: level of use, use of asset for civil defense and emergency activities, degree of redundancy, cost to replace, economic loss, general environmental impacts, cultural value, and potential loss of life.

### B. 811 Middle Street

<table>
<thead>
<tr>
<th>Societal Value of Asset</th>
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<tbody>
<tr>
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<tr>
<td>Recovery Time Needed</td>
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The 811 Middle Street facility houses 1800 employees, 531 buses, and 166 vehicles for TheHandi-Van. TheBus has a weekday ridership of 236,000 people and serves 100 different bus routes including express routes, community circulator routes, and urban feeder routes. TheHandi-Van’s daily weekday ridership is 2,800 customers. When looking at this asset for the combined TheBus and TheHandi-Van Baseyard and Intermodal Transit Center, the team determined that the climate change variables of storm surge, sea level rise, and heavy rain/storm events would have a socioeconomic valuation of the asset of high. This is because the vehicles may be needed for evacuations, and the social value of providing mobility to the community makes this asset important.
These facilities have some redundancy, and the vehicles and equipment have some mobility. The Pearl City/Manana Baseyard can provide some redundancy for TheBus and TheHandi-Van operations in the event of a storm. The buses and TheHandi-Van vehicles are normally not at the facility because they are used for islandwide evacuation in the event of an emergency. TheBus keeps approximately two days of diesel fuel for backup at 811 Middle Street with another two days of backup at the Pearl City/Manana Baseyard. Possibly their largest issue, like on Kauai after Hurricane Iniki, would be getting drivers and other employees to report back to work following an emergency event.

### C. 727 Kakoi Street

<table>
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<th>Societal Value of Asset</th>
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<tbody>
<tr>
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<tr>
<td>Recovery Time Needed</td>
<td>MODERATE</td>
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The asset will be affected by sea level rise. The team recommended that the HDOT Highways Division Oahu District Baseyard at 727 Kakoi Street in Mapunapuna be relocated because of sea level rise. By 2100, sea level rise models show the access road to the baseyard potentially underwater up to 12 hours per day. The baseyard is also along Moanalua Stream, and as discussed earlier in this section, is in an area that has been developed by the placement of landfills over time.

However, it was felt that the baseyard asset is important because it houses the equipment and manpower for cleanup of roads and highways should that be needed. There should be enough notice to move all of the vehicles and equipment to strategic locations in advance of a storm so that the baseyard vehicles would be available to clear roads.

### 3.3 Risk Assessment for Honolulu International Airport

#### A. Sea Level Rise: (see maps in Appendix D)

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>TheBus 811 Middle Street</th>
<th>Low Vulnerability, Low Structural Impact</th>
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<tbody>
<tr>
<td>HDOT Highways Division Oahu District Baseyard 727 Kakoi Street</td>
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<tr>
<td>Honolulu International Airport and Access</td>
<td>Low Vulnerability, Low Structural Impact</td>
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<tr>
<td>Risk Level in Year 2100</td>
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<td>Honolulu International Airport and Access</td>
<td>Low-Moderate Vulnerability, Low Structural Impact</td>
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</tbody>
</table>

**Reasons & Discussion**

While the 811 Middle Street facility is currently in a flood zone, its existing ground elevation gives it a low vulnerability and impact rating from sea level rise in 2050. Because this facility is adjacent to Kalihi Stream, situated at a bend in the stream channel, it may suffer more flooding by 2100 due to the combined effects of sea level rise and increased runoff intensity. This is because the bend in Kalihi Stream forms a sharp 90 degree deflection as circled in Figure 16, which may experience increased stream bank scour and become a collection point for mud and debris from upstream. The collection of debris and mud, coupled with high tide would make this asset more prone to flooding than already occurs.

![Figure 16: Aerial Photo of Kalihi Stream at 811 Middle Street](image)

The sea level rise model for the year 2100 shows that Kilihau Street, which is the primary access to Kakoi Street from Rt-92, Nimitz Highway, may flood for a minimum of 12 hours a day, making the HDOT Highways Division Oahu District Baseyard inaccessible from Rt-92, Nimitz Highway. Sea water has historically flooded the area, coming out of storm drain inlets at high tide, and this asset may also experience direct inundation from the adjacent Moanalua Stream. This is a likely and severe impact, meriting consideration of moving the District offices to a less vulnerable location.

The Reef Runway provides an approximately 8,000 feet long buffer from the ocean for the Honolulu International Airport terminals. In addition, the Reef Runway has a nearly 700 foot perimeter buffer from the ocean, surrounding the runway, so while the buffer area as well as some low spots that are in between the runways could all be inundated with seawater, the runway itself may still be able to function.
Figure 17: Street View of HDOT Oahu District Highways Baseyard

The main portions of Honolulu International Airport Terminals and runways shared with Joint Base Pearl Harbor Hickam may experience sea level rise in areas that are in between the runways, but the runways themselves may still be able to function in 2050 and 2100.

B. Storm Surge: (see map in Appendix D)

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>TheBus 811 Middle Street</th>
<th>HDOT Highways Division Oahu District Baseyard 727 Kakoi Street</th>
<th>Honolulu International Airport and Access</th>
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</tr>
</tbody>
</table>
Reasons & Discussion

The storm surge modeling is based on a Category 4 storm center passing within approximately 100 miles west of Honolulu Harbor, putting this transportation asset in the eastern hemisphere or northeastern quadrant of the storm. This is the most powerful part of the hurricane.

At the 811 Middle Street facility, if the modeled hurricane occurred during high tide, portions of the facility may flood with nearly 10 feet of water, according to the storm surge modeling map. This is because the dredged channels could amplify the effect of storm surge, and the streams could channel the surging water further inland. Sea level rise in 2050 and 2100 will only amplify this effect. The team also noted that debris and mud clogging Kalihi Stream could make this asset more prone to flooding during a storm surge. Currently, the mud has formed “islands” in the middle of the stream, which have vegetation growing on them.

In Mapunapuna, where the 727 Kakoi Street HDOT Highways Division Oahu District Baseyard facility is located, the City & County of Honolulu is currently installing one-way valves in the drainage system in order to reduce the current flooding of the area. With the amount of sea water inundation the area is already experiencing, the pavement will fail sooner, especially in parking lots that have heavy loads such as the baseyard. In addition, the Moanalua Stream banks are not hardened, so they could be prone to increased erosion over time.

Access to the airport through Middle Street and parts of Lagoon Drive may be impassable with a storm surge of five feet, however, alternate access to the airport exists through the Interstate H-1 Freeway viaduct. Sea level rise may add an additional foot of water in 2050 and three feet or more of water in 2100, further complicating any transportation links with the airport area.

In the Category 4 hurricane modeling scenario, the Reef Runway could be completely inundated with sea water during a storm surge from a hurricane coming ashore at Ewa, which is the worst case scenario. The airport may be unusable and may have to shut down, including runways shared with Joint Base Pearl Harbor-Hickam. This scenario exists in present day, and it is likely to be exacerbated with the sea level rise predicted for 2050 and 2100.

C. Wind

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>TheBus 811 Middle Street</th>
<th>Low Vulnerability, Low Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HDOT Highways Division Oahu District Baseyard 727 Kakoi Street</td>
<td>Low Vulnerability, Moderate Structural Impact</td>
</tr>
<tr>
<td></td>
<td>Honolulu International Airport and Access</td>
<td>Low Vulnerability, Low Structural Impact</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Level in Year 2100</th>
<th>TheBus 811 Middle Street</th>
<th>Low-Moderate Vulnerability, Low Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HDOT Highways Division Oahu District Baseyard 727 Kakoi Street</td>
<td>Low Vulnerability, Moderate Structural Impact</td>
</tr>
<tr>
<td></td>
<td>Honolulu International Airport and Access</td>
<td>Low Vulnerability, Low Structural Impact</td>
</tr>
</tbody>
</table>
Reasons & Discussion

TheBus 811 Middle Street hosts communication equipment on its rooftop, which may be susceptible to wind damage in a storm, hurricane, or wind gust event. This impact from wind damage is seen as growing with wind velocities predicted to increase by 25% by 2100.

The HDOT Highways Division Oahu District Baseyard at 727 Kakoi Street has a satellite dish and 800 MHz antenna system on its rooftop and these may be vulnerable to high winds, especially with the predicted rise in wind velocity.

In the event of high winds, such as tropical storm events, the Honolulu International Airport may shut down and move planes until they can be safely returned to use at the airport. The asset itself may not be as vulnerable to high winds.

D. High Intensity Rainfall

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>TheBus 811 Middle Street</th>
<th>Moderate Vulnerability, High Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HDOT Highways Division Oahu District Baseyard 727 Kakoi Street</td>
<td>Moderate Vulnerability, High Structural Impact</td>
</tr>
<tr>
<td></td>
<td>Honolulu International Airport and Access</td>
<td>Low Vulnerability, Low Structural Impact</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Level in Year 2100</th>
<th>TheBus 811 Middle Street</th>
<th>High Vulnerability, High Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HDOT Highways Division Oahu District Baseyard 727 Kakoi Street</td>
<td>High Vulnerability, High Structural Impact</td>
</tr>
<tr>
<td></td>
<td>Honolulu International Airport and Access</td>
<td>Moderate Vulnerability, Low Structural Impact</td>
</tr>
</tbody>
</table>

Reasons & Discussion

Kalihi Stream appears to be susceptible to a decrease in discharge capacity as a result of sediment and debris accumulation, especially near the channel bend adjacent to the 811 Middle Street facility. The debris has deposited and formed islands in the middle of the stream, which will cause the stream to backup when large debris from upstream accumulate.

The HDOT facility at 727 Kakoi Street is very susceptible to flooding, due to the adjacent Moanalua Stream as well as the current poor surface drainage condition in the larger Mapunapuna area. During heavy rains, which are predicted to increase in intensity over time, the stream banks may overflow into the facility, and result in flooding.

Airport runways typically have a thicker pavement section and are able to withstand greater loads in comparison to vehicle roadways. The runways may also be slower to drain than roadways due to flat grades. The HDOT Airports Division is required by the Federal Aviation Administration to maintain the runway pavements in good condition. For these reasons, the heavy rainfall risk levels were ranked as low and low-moderate for years 2050 and 2100, respectively.
E. Air Temperature

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>TheBus 811 Middle Street</th>
<th>Low Vulnerability, Low Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDOT Highways Division Oahu District Baseyard 727 Kakoi Street</td>
<td>Low Vulnerability, Low Structural Impact</td>
<td></td>
</tr>
<tr>
<td>Honolulu International Airport and Access</td>
<td>Low Vulnerability, Low Structural Impact</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Level in Year 2100</th>
<th>TheBus 811 Middle Street</th>
<th>Low Vulnerability, Low Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDOT Highways Division Oahu District Baseyard 727 Kakoi Street</td>
<td>Low Vulnerability, Low Structural Impact</td>
<td></td>
</tr>
<tr>
<td>Honolulu International Airport and Access</td>
<td>Low Vulnerability, Low Structural Impact</td>
<td></td>
</tr>
</tbody>
</table>

Reasons & Discussion

While the air temperature is rising at 0.16°F per decade, with an increase of 1.6°F by 2100 from 2000 levels, the air temperature was not deemed to have any significant effect on this transportation asset over time.

The team noted that higher air temperatures may require a longer runway for a slightly longer takeoff distance as hotter air is generally less dense than colder air. Honolulu International Airport has the longest runway in the state.

3.4 Integrated Risk Assessment

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>TheBus 811 Middle Street</th>
<th>LOW-MODERATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDOT Highways Division Oahu District Baseyard 727 Kakoi Street</td>
<td>MODERATE-HIGH</td>
<td></td>
</tr>
<tr>
<td>Honolulu International Airport</td>
<td>HIGH</td>
<td></td>
</tr>
<tr>
<td>Honolulu International Airport Access</td>
<td>LOW-MODERATE</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Level in Year 2100</th>
<th>TheBus 811 Middle Street</th>
<th>MODERATE-HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDOT Highways Division Oahu District Baseyard 727 Kakoi Street</td>
<td>HIGH</td>
<td></td>
</tr>
<tr>
<td>Honolulu International Airport</td>
<td>HIGH</td>
<td></td>
</tr>
<tr>
<td>Honolulu International Airport Access</td>
<td>LOW-MODERATE</td>
<td></td>
</tr>
</tbody>
</table>

Reasons & Discussion

The higher ranking for the Honolulu International Airport asset was due to the impact of storm surge combined with predicted sea level rise. The HDOT Highways Division Oahu District Baseyard and TheBus facilities are both located adjacent to large streams, which increase their climate change vulnerability. The Honolulu International
Airport is directly on the ocean, and offshore dredged channels could increase the effects of a storm surge. While many of the airport access roads may be impassable in a storm event and during high tide, alternate access routes do exist, so airport access roadways did not receive as high of an integrated risk vulnerability score.

Of the assets considered in this group:

- The Honolulu International Airport received a rank of HIGH due to its intrinsic value to the island economy as well as its integral transportation link to the outside world;
- TheBus/TheHandi-Van Maintenance Facility is least vulnerable, but due to its value to society, should continue to be monitored for the effects of climate change; and
- The HDOT Oahu District Baseyard is recommended for relocation over the next 20 years due to the effects of sea level rise by the end of this century.

### 3.5 Data Sources


Sea Level Modeling by University of Hawaii Coastal Geology Group, C. Fletcher and M. Barbee. 2011.


Section 4.0 Risk Assessment of Kalaeloa Barbers Point Area

Asset Group: Kalaeloa

Facilities Named in this Asset:
- Kalaeloa Airport
- Kalaeloa Barbers Point Harbor
- Campbell Industrial Park
- Kalaeloa Boulevard, Malakole Street, and Enterprise Road access to Kalaeloa assets

Figure 18: GIS Map of Kalaeloa Asset

4.1 Asset Description

Kalaeloa Airport, Kalaeloa Barbers Point Harbor, and Campbell Industrial Park are on the south-western coastal plain of the island of Oahu. This area was formerly known as Barbers Point, and many people still refer to it as such.

Kalaeloa Airport is within the former Barbers Point Naval Air Station which closed in July 1999. It currently serves the U.S. Coast Guard Air Station search-and-rescue helicopters as well as general aviation aircraft, and includes pilot training facilities.
Kalaeloa Barbers Point Harbor contains several specialized handling facilities such as a bulk coal unloader system and a pneumatic cement unloading system. The harbor includes pipelines for liquid fuels that are offloaded there. It is the second busiest harbor in the state, next to Honolulu Harbor. Its main channel entrance measures approximately 3,100 feet long by about 450 feet wide and averages about 42 feet in depth. The Barge Basin is the outline of the original Barbers Point Harbor. Kalaeloa Barbers Point Harbor is adjacent to the privately-owned Ko Olina Beach Marina and Resort as well as the Campbell Industrial Park.
<table>
<thead>
<tr>
<th>Kalaeloa Barbers Point Harbor Pier</th>
<th>Berth Length (Feet)</th>
<th>Design Depth at Pier (Feet)</th>
<th>Principal Cargo/Pier Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barge Basin</td>
<td>255</td>
<td>16</td>
<td>Liquid-bulk cargo and pipelines, Scrap metal and sand.</td>
</tr>
<tr>
<td>P-3</td>
<td></td>
<td></td>
<td>Dry dock</td>
</tr>
<tr>
<td>Ferry/Tug Pier</td>
<td>150 each side</td>
<td>38</td>
<td>Ferry terminal</td>
</tr>
<tr>
<td>P-5A</td>
<td>300</td>
<td>38</td>
<td>Neo-bulk cargo, petroleum, and scrap metal</td>
</tr>
<tr>
<td>P-5B</td>
<td>800</td>
<td>38</td>
<td>Liquid-bulk cargo and pipelines, Neo-bulk cargo and scrap metal</td>
</tr>
<tr>
<td>P-6</td>
<td>800</td>
<td>38</td>
<td>Liquid-bulk cargo and pipelines, Dry- and neo-bulk cargos and scrap metal, Dry-bulk unloader and storage</td>
</tr>
<tr>
<td>P-7</td>
<td>800</td>
<td>38</td>
<td>Dry-bulk cargo</td>
</tr>
</tbody>
</table>


Campbell Industrial Park contains nearly 250 businesses, energy facilities, and warehouses for much of the goods that come into Hawaii for distribution, such as groceries and building materials. It is the largest industrial park in the state.

Figure 21: Chevron Refinery at Campbell Industrial Park

Source: SSFM International
Between Campbell Industrial Park and Kalaeloa Airport is the Saratoga Street Channel, which is concrete lined after Point Cruz Road and includes a small beach at the point where it joins the ocean. Beyond that is marsh/wetland area. The Saratoga Street Channel has increased in length over time, moving it further inland due to erosion from the ocean.

The shoreline fronting these assets is generally comprised of hardened materials including coralline reef and coral-algal limestone reef materials with surficial calcareous sediments. The shoreline is not reclaimed land like Sand Island and is less prone to erosion. The entire area has an elevation of approximately +9 to +12 feet Mean Sea Level (MSL).

### 4.2 Importance of the Asset Group to Society

#### A. Kalaeloa Airport

<table>
<thead>
<tr>
<th>Societal Value of Asset</th>
<th>LOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of Use</td>
<td>LOW</td>
</tr>
<tr>
<td>Degree of Redundancy</td>
<td>MODERATE</td>
</tr>
<tr>
<td>Cost to Replace</td>
<td>LOW-MODERATE</td>
</tr>
<tr>
<td>Economic Loss</td>
<td>LOW</td>
</tr>
<tr>
<td>Environmental Impacts</td>
<td>LOW</td>
</tr>
<tr>
<td>Cultural Value</td>
<td>LOW</td>
</tr>
<tr>
<td>Loss of Life</td>
<td>LOW</td>
</tr>
<tr>
<td>Recovery Time Needed</td>
<td>MODERATE</td>
</tr>
</tbody>
</table>
Kalaeloa Airport facility was designated Coast Guard Air Station Barbers Point in 1965 and continues in that function today. It is the only Coast Guard aviation unit located in the 14th Coast Guard District, which includes the state of Hawaii and territory of Guam. Their C-130 Hercules aircraft and H-65 Dolphin helicopters perform search-and-rescue missions within the central Pacific maritime region. Aircraft also conduct water pollution patrols in the Hawaiian Islands.

The Kalaeloa Airport accounts for 132,327 annual takeoffs and landings combined. The flights from this airport are mainly for pilot training exercises as well as Coast Guard aircraft discussed earlier in this section. The Coast Guard aircraft can be used in emergencies, catastrophes, and civil defense actions. Kalaeloa Airport serves as the backup airport to Honolulu International Airport. The team determined that aside from the Coast Guard, this airport has minimal terminal infrastructure. Because the airport does not serve commercial airlines and does not receive any goods, the team gave this asset a socioeconomic valuation of low.

B. Campbell Industrial Park

<table>
<thead>
<tr>
<th>Societal Value of Asset</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of Use</td>
<td>HIGH</td>
</tr>
<tr>
<td>Degree of Redundancy</td>
<td>LOW</td>
</tr>
<tr>
<td>Cost to Replace</td>
<td>HIGH</td>
</tr>
<tr>
<td>Economic Loss</td>
<td>HIGH</td>
</tr>
<tr>
<td>Environmental Impacts</td>
<td>HIGH</td>
</tr>
<tr>
<td>Cultural Value</td>
<td>LOW</td>
</tr>
<tr>
<td>Loss of Life</td>
<td>LOW</td>
</tr>
<tr>
<td>Recovery Time Needed</td>
<td>HIGH</td>
</tr>
</tbody>
</table>

Campbell Industrial Park contains nearly 250 businesses including the only fuel refineries on Oahu: Chevron and Tesoro. These refineries have underground pipelines that travel approximately ten miles toward Downtown Honolulu.

H-POWER, which is a City & County of Honolulu garbage-to-energy power plant, is also located at Campbell Industrial Park. H-POWER processes up to 422,605 tons of refuse annually; derived fuel generates up to 57 megawatts of energy per day for the Hawaiian Electric Company. This is enough electricity to power 45,000 residences on Oahu and meets 4.5% of Oahu’s energy need. AES Power Plant is the only coal-fired power plant in the state of Hawaii and represents about 10% of Oahu’s commercial electricity supply, burning 650,000 tons of coal per year.

There are two refineries operating in Campbell Industrial Park by Chevron and Tesoro. In addition, H-POWER and AES Coal combined generate nearly 15% of the power needs for the island of Oahu. For these reasons, the team gave a high socioeconomic value to this asset.

The fuel tanks are approximately 450 meters from the ocean, which equates to one-third of a mile. This set back should be helpful during storm surge. In addition, the fuel is offloaded at mooring buoys off the coast of Kalaeloa. These mooring buoys are under the jurisdiction of the Coast Guard, and there are contingency plans in place in case of disasters.
There are no residential structures in this area, but with about 250 commercial businesses, evacuation of the employees would be of concern during a heavy storm. Another concern is the amount of petroleum and processing waste that could experience leakage during a heavy storm.

H-POWER processed 422,605 tons of refuse in the calendar year 2009. This is the majority of the 62% of the island’s waste that is diverted from the Waimanalo Gulch Landfill and Construction & Demolition Landfill, both located along the Waianae Coast. H-POWER has not shut down for any storms since it opened in 1990, but should a severe storm or hurricane cause the plant to cease operations, this would have a severe effect on the capacity of the landfills as well as a reduction in the generation of electricity for the island.

C. Kalaeloa Barbers Point Harbor

<table>
<thead>
<tr>
<th>Societal Value of Asset</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of Use</td>
<td>HIGH</td>
</tr>
<tr>
<td>Degree of Redundancy</td>
<td>LOW</td>
</tr>
<tr>
<td>Cost to Replace</td>
<td>HIGH</td>
</tr>
<tr>
<td>Economic Loss</td>
<td>HIGH</td>
</tr>
<tr>
<td>Environmental Impacts</td>
<td>MODERATE</td>
</tr>
<tr>
<td>Cultural Value</td>
<td>LOW</td>
</tr>
<tr>
<td>Loss of Life</td>
<td>LOW</td>
</tr>
<tr>
<td>Recovery Time Needed</td>
<td>MODERATE</td>
</tr>
</tbody>
</table>

Kalaeloa Harbor plays an important strategic role in the overall state transportation system due to the kind of cargo it receives as well being the backup harbor for Honolulu Harbor. Liquid fuel is discharged through pipelines directly to the two refineries at Campbell Industrial Park. Bulk coal is offloaded along a 1.6 mile conveyor belt straight into AES Coal at Campbell Industrial Park.

Kalaeloa Barbers Point Harbor serves as the lifeline for energy for the state. If the harbor lost the ability to offload oil for electricity generation and for vehicle fuel, it would have severe and dire consequences to the islands’ residents and state’s economy. This harbor is where the majority of bulk construction materials are offloaded, and these same materials would be necessary for any rebuilding efforts.

While there are no residents at the harbor, the nearby Ko Olina Resort development does have approximately 3,000 residents. This figure does not count tourists in the resort complex.

The pier structures at this harbor are higher than the area’s elevation. There is a “resonance problem,” also known as a seiche, at this harbor, where the currents and tides are amplified in the basin of the harbor, adding to the complexity of offloading. This is because the seiche causes the cargo ships to move so much, the offloading must be timed correctly with the currents and the tides in order to steady the ship as much as possible.

The team recommends that further study be given by conducting a cost benefit analysis for the extreme case scenario of potentially six feet of sea level rise affecting Kalaeloa Harbor. The analysis would compare the cost/benefit of retreating the harbor facilities further inland vs. raising the harbor piers. This extreme case scenario of six feet in sea level rise is not predicted to occur until 2100, giving time to modify the harbor. Due to the time for harbor modification, the socioeconomic risk for sea level rise is lower than for storm surge, which can occur at any time. The team also recommends further study be given to the resonance problem at the Kalaeloa
Barbers Point Harbor, with the consideration of a breakwater or other engineering to combat the *seiche* phenomena.

### 4.3 Risk Assessment for Kalaeloa Barbers Point Area

**A. Sea Level Rise: (see maps in Appendix D)**

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Low Vulnerability, Low Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>Low-Moderate Vulnerability, Low-Moderate Structural Impact</td>
</tr>
</tbody>
</table>

*Reasons & Discussion*

The ground surface elevations within the Kalaeloa district typically range between +9 and +12 feet MSL, and the named assets are located fronting or in close proximity to the ocean. There are localized low-lying areas throughout Campbell Industrial Park, and these are usually basins that have been constructed around facilities such as the Chevron and Tesoro refineries and the City’s H-POWER plant.

The sea level rise model for 2050 of one foot of sea level rise showed low impact and vulnerability to the entire area.

The sea level rise model for 2100 of three feet showed a moderate impact to each of the assets. The model, with respect to Kalaeloa Barbers Point Harbor showed most of the predicted sea level rise affecting the Barge Basin, which is the site of the original Barbers Point Harbor and the oldest developed portion of that asset. Most of the potential land loss modeled was beside Pier 7 in the area adjacent to the Ko Olina small boat harbor. With three feet of sea level rise at Campbell Industrial Park, the Chevron Hawaii Refinery, which is along the shore, showed a considerable vulnerability due to its lower ground surface elevation. The western shore of the industrial park shows the greatest potential loss of land with the entire existing shoreline becoming submerged. Interestingly, the Saratoga Channel did not show loss of land with modeled three-foot sea level rise. The sea level rise model shows the rising sea level encroaching on the easternmost runway at Kalaeloa Airport as well as the adjacent coastline. There is an existing low elevation/landlocked area modeled to have seawater encroachment between the two existing runways. Existing access roads to the area appear to remain passable with the predicted three feet of sea level rise.

**B. Storm Surge**

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>High Vulnerability, High Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>High Vulnerability, High Structural Impact</td>
</tr>
</tbody>
</table>

*Reasons & Discussion*

While storm surge model maps are not available for the Kalaeloa area, the team used available sea level rise modeling to identify low lying areas that may be susceptible to storm surge. The Kalaeloa district is generally between +9 and +12 feet of elevation, and each asset is located on or very near the ocean. While streams are usually a conduit for inland storm surge encroachment, the existing Saratoga Channel’s narrow construction appears to restrict incoming wave energy. Some Kalaeloa Barbers Point Harbor surge has been observed during current periods of elevated wave action.
The majority of the Kalaeloa area roadways may not be affected by storm surge, except the west end of Malakole Street in Campbell Industrial Park and the south end of Coral Sea Road surrounding Kalaeloa Airport.

In addition, the existing coastline of the Campbell Industrial Park and Kalaeloa Airport contains vegetation, which could serve as a buffer zone for storm surge if that area is not developed.

While harbors and reefs may amplify storm surge, it is not known how storm surge may specifically affect Kalaeloa Barbers Point Harbor because the team did not have a storm surge map or model available for that asset.

C. Wind

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Moderate Vulnerability, Moderate Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>Moderate Vulnerability, Moderate Structural Impact</td>
</tr>
</tbody>
</table>

Reasons & Discussion

If the eye of a Category 4 hurricane were to impact the Waianae Coast, Kalaeloa and Campbell Industrial Park could sustain the most damage because they would be in the hurricane’s forward right quadrant, which is where the winds reach the highest velocity.

The Campbell Industrial Park Area is served by overhead electricity lines and, at the same time, houses two electricity generating facilities: AES Coal and H-POWER. AES Coal at the Campbell Industrial Park Area is connected to Kalaeloa Barbers Point Harbor by a 1.6 mile conveyor belt so that coal can be directly offloaded from cargo ships to the facility. This infrastructure may be susceptible to wind damage. The AASHTO structural engineering wind loads for cantilevered traffic signals and overhead lines is 105 MPH, which is a Category 2 hurricane.

D. High Intensity Rainfall

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Low-Moderate Vulnerability, Low-Moderate Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>Low-Moderate Vulnerability, Moderate Structural Impact</td>
</tr>
</tbody>
</table>

Reasons & Discussion

The two refineries and H-POWER as well as the parking lot area around the Chevron refinery are all in low lying areas of Campbell Industrial Park. These areas take several days to drain when there is heavy rainfall, leaving ponding water until it evaporates. The typical geologic stratigraphy is generally thin, low infiltration capacity surface soils overlying coralline reef/coral algal limestone having generally high but variable infiltration capacity and transmissive permeability.

There are no bridges in this area, so there is no bridge foundation scour to consider. With an increase in storm events of 15-30% by 2050 and 30-60% by 2100, the team predicted more flooding and ponding of parking and roadway areas. Due to alternative access to Campbell Industrial Park via Renton Road to Saratoga Road to Malakole Street and alternative access of Enterprise Road to the Kalaeloa Airport, the team ranked this climate change variable with a moderate impact.
E. Air Temperature

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Low Vulnerability, Moderate Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>Low Vulnerability, Moderate Structural Impact</td>
</tr>
</tbody>
</table>

**Reasons & Discussion**

While the air temperature is rising at 0.16°F per decade, with an increase of 1.6°F by 2100 from 2000 levels, the air temperature was not deemed to have a significant effect on this transportation asset in either time frame.

### 4.4 Integrated Risk Assessment

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Kalaeloa Airport: LOW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kalaeloa Barbers Point Harbor: MODERATE</td>
</tr>
<tr>
<td></td>
<td>Campbell Industrial Park: MODERATE</td>
</tr>
<tr>
<td></td>
<td>Access Roads: LOW</td>
</tr>
<tr>
<td>Risk Level in Year 2100</td>
<td>Kalaeloa Airport: LOW</td>
</tr>
<tr>
<td></td>
<td>Kalaeloa Barbers Point Harbor: HIGH</td>
</tr>
<tr>
<td></td>
<td>Campbell Industrial Park: HIGH</td>
</tr>
<tr>
<td></td>
<td>Access Roads: LOW-MODERATE</td>
</tr>
</tbody>
</table>

**Reasons & Discussion**

The Kalaeloa asset area is arid, close to the ocean, and has a relatively high groundwater level. The lowest ground surface elevations of this asset group are at Campbell Industrial Park, and these local low elevations appear to be related to containment basins that were constructed as part of the facilities for the Chevron and Tesoro refineries and H-POWER. The typical ground surface elevation is generally between +9 and +12 feet MSL, excluding the containment basins.

Because sea level rise was shown not to affect the area greatly in 2050; there are no bridges; and there is alternative roadway access should downed poles or debris shut down one of the roads, the team ranked the asset between low and moderate for vulnerability and impact in 2050.

Sea level rise effects became more pronounced in 2100, especially around Campbell Industrial Park and part of the Kalaeloa Airport shoreline. Historical hurricane tracks show tropical storms and hurricanes passing between Oahu and Kauai, which could put Kalaeloa at the most vulnerable part of a hurricane – the forward right quadrant. Temperature rise was shown not to be a significant factor to consider.

Based on these factors, the team ranked Kalaeloa Airport as low for the preliminary integrated risk. Access roads were ranked low-moderate for the preliminary integrated risk because there is alternative roadway access. Kalaeloa Barbers Point Harbor and Campbell Industrial Park may sustain the greatest adverse effects due to climate change, and they were given a high ranking.
4.5 Data Sources


Department of Navy Base Realignment and Closure Program Management Office Website:  

Fletcher, Charles H.  *Hawaii’s Changing Climate, Briefing Sheet*.  University of Hawaii Sea Grant College Program, Center for Climate Adaptation and Policy. Honolulu. 7 pages. 2010.


Sea Level Modeling by University of Hawaii Coastal Geology Group, C. Fletcher and M. Barbee.  2011.
Section 5.0 Risk Assessment of Three Waikiki Bridges

Asset Group: Three Waikiki Bridges

Facilities Named in this Asset:
- Ala Moana Boulevard Bridge
- Kalakaua Avenue Bridge
- McCully Street Bridge

5.1 Asset Description

All three bridges pass over the Ala Wai Canal and are less than one mile apart. Each bridge provides vehicle and pedestrian access to a different section of Waikiki. All three bridges have sidewalks on both sides for pedestrian access. Currently, at high tide, paddlers and other canal users are unable to pass beneath some spots of all bridges, when clearance beneath the bridge is approximately less than four feet.

A. Ala Moana Boulevard Bridge

The Rt-92 Ala Moana Boulevard Bridge is actually two bridges joined together, with a concrete median barrier separating each direction of traffic. Each side of the bridge is three lanes wide, and it is the widest of the three bridges. The sides of the bridge have metal railings on top of concrete walls. HDOT Highways Division owns Ala Moana Bridge on Rt-92.
This is a three span concrete slab bridge with a concrete sub-structure.

According to the latest available HDOT inspection report (2009):

- The deck has transverse cracks and small potholes over the abutments, numerous delaminations and spalls with exposed rebar on the outside edge and random hairline cracks and spalls on the sides. There is leakage and water stains on the piers.
- The substructure and superstructure have large spall and exposed rebar on the upstream outside edge of the deck.
- The channel walls are concrete. The southwest channel wall shows undermining.

Figure 24: Ala Moana Bridge Sidewalk

Source: Wikipedia/Travis Thurston

Figure 25: Ala Wai Canal Passing Beneath the Kalakaua Avenue Bridge

Source: GoogleEarth/Panaramio

B. McCully Street Bridge

McCully Street Bridge is located between Kapiolani Boulevard and Ala Wai Boulevard. It is owned by the City & County of Honolulu. It is a seven-span reinforced concrete slab bridge servicing a five lane road and is 82 feet 6 inches wide and 169 feet long. The roadway surface is 70 feet wide, with a 6 feet wide raised sidewalk on each side. The clearance from the bottom of the slab to the unlined stream channel varies, but is about 21 feet 5 inches maximum. From the bottom of the bridge to the average water surface level, clearance at low tide is approximately six feet and only three feet at high tide. Sidewalks are concrete with two feet 10 inches high guardrails on each side.
According to the latest available HDOT inspection report (2009):

- The bridge is considered to be in satisfactory to good condition with deficiencies such as cracks in the concrete deck and spalls at the deck drains, delaminations, spalls with exposed rebar and crack with efflorescence on the slab soffit, and moderate cracking and spalls in the piles.
- The deck is in good condition, with some cracks in the asphalt concrete (AC) and ragged edges and small potholes along the gutters. The sidewalks had cracks and a spall on the south end and on the north end.
- The superstructure is in good condition. An upstream utility pipe was heavily rusted and concrete supports had heavy spalling with exposed rebar, delaminations, and cracks with efflorescence.
- The substructure is in satisfactory condition with cracks in the Concrete-Reinforced-Masonry (CRM) wall in the south abutment and cracks in the north abutment. There were missing rocks and areas of undermining on the north abutment. The piles had delaminations and spalls with exposed rebar. Pile caps had cracks, delaminations, and spalls.
- The channel is in good condition. The Ala Wai Canal invert is unlined, but there are low CRM walls on both sides. The invert is heavily silted. Scour was noted beneath the north abutment along the CRM wall.
- The Load Resistance Rating Factor Rating, Inventory is 131 and Operating Rating is 170.

There are several utility conduits under the bridge. These include six electrical conduits on the northern side, four telephone conduits in the middle, a water line, and one six-inch gas line on the southern side.
Figure 27: McCully Bridge Downstream Elevation

Source: C&C Department of Design & Construction

Figure 28: McCully Bridge Edge Spall
Spanning Between Piers 3 and 4 on Downstream Face

Source: C&C Department of Design and Construction
C. Kalakaua Avenue Bridge

Kalakaua Bridge is the oldest of the three bridges, built in 1929 and, at over 50 years old, is documented as an historic bridge which is owned by the City & County of Honolulu.

This is a three-span reinforced concrete slab bridge servicing a four lane road. It is 73 feet 4 inches wide and 147 feet 8 inches long. Concrete guardrails are constructed on top of reinforced concrete and measure three feet high on each side.
The latest inspection report (MKE Associates, 2009) rates the bridge as satisfactory to good condition.

- All three arch span soffits have cracks with wet efflorescence, spalls, and delamination. The piers and abutments have cracks, delamination, and efflorescence. Foundations were assumed to be in satisfactory condition, with no signs of distress.
- The bridge deck was in good condition, with numerous cracks in the AC pavement, and unraveling near the curbs at the south upstream end. Mid-span had several shallow spalls. Downstream had grid patterned cracking and a two-inch spall with exposed rebar.
- Superstructure is in fair condition. Delaminations and transverse cracks along with some spalling were observed.
- Substructure is in good condition with vertical cracking of both abutments and horizontal cracking of the north abutment.
- Underwater inspection showed no damage to submerged portions of piles, piers, or abutment faces.
- The channel under the bridge is in good condition. Flow of water is gentle, with no vegetation or debris observed.

The bridge carries several utility lines into Waikiki, including a gas line, sewer line, a water line, and PVC conduits for traffic signals and street lights.
Ala Wai Canal was last dredged in 2003, and the previous dredging was 25 years earlier in 1978. Makiki, Manoa, and Palolo Streams are tributaries to the canal and, over time, sediment accumulates, creating shallow depths within the waterway. The canal functions as a built-in detention basin for flood waters.

Because all three bridges are located in different areas along the Ala Wai Canal, the team separated the risk assessments for each bridge, for the years 2050 and 2100.

5.2 Importance of the Asset Group to Society

<table>
<thead>
<tr>
<th></th>
<th>Any One Bridge</th>
<th>All Three Bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Societal Value of Asset</td>
<td>MODERATE</td>
<td>MODERATE</td>
</tr>
<tr>
<td>Level of Use</td>
<td>MODERATE</td>
<td>HIGH</td>
</tr>
<tr>
<td>Degree of Redundancy</td>
<td>HIGH</td>
<td>LOW</td>
</tr>
<tr>
<td>Cost to Replace</td>
<td>MODERATE</td>
<td>HIGH</td>
</tr>
<tr>
<td>Economic Loss</td>
<td>LOW</td>
<td>MODERATE-HIGH</td>
</tr>
<tr>
<td>Environmental Impacts</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Cultural Value</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Loss of Life</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Recovery Time Needed</td>
<td>MODERATE</td>
<td>MODERATE-HIGH</td>
</tr>
</tbody>
</table>
These three bridges are the only access into Waikiki from the western end of Honolulu. According to HDOT, the Annual Average Daily Traffic (AADT) has fluctuated quite a bit over the past decade due to large variations in the economy and tourism. As of 2009, the AADT for each of the bridges is as follows:

- Ala Moana Boulevard Bridge: 35,300
- Kalakaua Avenue Bridge: 34,600
- McCully Street Bridge: 35,799

It is important to note that the fluctuations in the past decade have shown as many as 10,000 more vehicles per day, and these are vehicles of all sizes including passenger cars, tour buses, and delivery trucks.

While these three bridges combined carry in excess of 100,000 vehicles per day across the Ala Wai Canal, they also serve another function. McCully Street and Kalakaua Avenue bridges both contain critical utility lines that cross on their sides or beneath them and these bridges also serve as emergency evacuation routes.

Kapahulu Avenue provides another access to Waikiki from the eastern end of Honolulu. The bridges are crucial to tourism, not only for the tourists to enter and exit Waikiki, but also for all of the service vehicles that are associated with tourism such as tour buses and delivery trucks as well as access for people who live and work in Waikiki. Currently there are 18,000 residents in Waikiki, which may be defined as being bounded by the Ala Wai Canal, including the Ala Wai Small Boat Harbor, following the Ala Wai Canal eastwards to Kapahulu Avenue, with the southern border being the ocean itself. Adjacent to Waikiki on the northwest end up to the Ala Wai Golf Course there are approximately 42,000 residents from Rt-92, Ala Moana Boulevard to McCully Street. Between the Ala Wai Golf Course and through Kapahulu Avenue and Diamond Head are an additional 14,000 residents, though these residents may be less apt to use any of the three bridges to access Waikiki because they are closer to Kapahulu Avenue, Montserrat Avenue, and Diamond Head Road.

At the time of writing this analysis, 2010 Census Data for jobs were not available. Past census data from the State Department of Business, Economic Development and Tourism (2002) indicate Waikiki accounts for over 73,000 jobs and over 1,600 businesses. These data were acquired before the economic slump that began in 2007. However, it is safe to say that Waikiki accounts for over 40% of all tourism dollars and close to 10% of all civilian jobs on Oahu.

Transportation planners must consider the tourists, residents, as well as employees when needing to evacuate Waikiki. The current tsunami evacuation plan is vertical. For other events that may have advance notice, such as severe storms and hurricanes, consideration should be given to the amount of traffic, pedestrian and vehicular, these three bridges can accommodate during an evacuation.

Both Kalakaua Avenue and McCully Street bridges carry various utilities on them and on to Waikiki. McCully Street Bridge is considered the more crucial of the two in the sense that it carries the electricity for Waikiki.

The Ala Wai Canal does not have a high clearance beneath any of the three bridges during high tide. During high tide today there is overtopping on the walls beneath McCully Street Bridge. All three bridges are vulnerable to sea level rise as the model shows the access to them would be cut off by 2100. Sea level rise would affect more than just the bridges in Waikiki as there could be severe erosion of the shoreline as well as flooding of the streets.
5.3 Risk Assessment for Three Waikiki Bridges

A. Sea Level Rise: (see maps in Appendix D)

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Ala Moana Boulevard Bridge</th>
<th>Low Vulnerability, Low Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kalakaua Avenue Bridge</td>
<td>Moderate Vulnerability, Moderate-High Impact</td>
</tr>
<tr>
<td></td>
<td>McCully Street Bridge</td>
<td>Low-Moderate Vulnerability, Low Impact</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Level in Year 2100</th>
<th>Ala Moana Boulevard Bridge</th>
<th>High Vulnerability, High Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kalakaua Avenue Bridge</td>
<td>High Vulnerability, High Impact</td>
</tr>
<tr>
<td></td>
<td>McCully Street Bridge</td>
<td>High Vulnerability, High Impact</td>
</tr>
</tbody>
</table>

Reasons & Discussion

Sea level rise should not significantly impact foundation scour resistance at the three bridges. Currently, they are all impacted by floodwater debris consisting of vegetation, refuse, and other discarded debris contained in the tributaries discharging to the Ala Wai Canal.

Because the existing banks of the canal are low in elevation, elevated water levels may spill over the banks rather than directly increase the flow velocity of the waterway. A rising tide moves opposite the canal discharge direction and reverses during falling tide. Canal flow velocity should be maximum during a falling tide combined with high channel volume discharge. Storm water infiltration and surface drainage may be reduced the greatest at this time, especially when combined with rising sea level rise effects.

All three bridges received a high vulnerability, high impact rating in 2100, because with three feet of sea level rise, roadway approaches on either end of all three bridges could be flooded, making access impossible.

B. Storm Surge: (see map in Appendix D)

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Ala Moana Boulevard Bridge</th>
<th>High Vulnerability, High Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kalakaua Avenue Bridge</td>
<td>Moderate Vulnerability, High Structural Impact</td>
</tr>
<tr>
<td></td>
<td>McCully Street Bridge</td>
<td>Moderate Vulnerability, Moderate Structural Impact</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Level in Year 2100</th>
<th>Ala Moana Boulevard Bridge</th>
<th>High Vulnerability, High Structural Impact</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Kalakaua Avenue Bridge</td>
<td>High Vulnerability, High Structural Impact</td>
</tr>
<tr>
<td></td>
<td>McCully Street Bridge</td>
<td>High Vulnerability, High Structural Impact</td>
</tr>
</tbody>
</table>

Reasons & Discussion

Storm surge magnitude is highly variable and depends upon the storm wind direction, velocity, and fetch relative to the landfall target. Storm frequency is predicted to increase 15-30% by 2050 over 2000 levels, and could increase by as much as 30-60% by 2100. This means storm surge, coupled with sea level rise, will only exacerbate the situation.
C. Wind

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Bridge Name</th>
<th>Vulnerability</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ala Moana Boulevard</td>
<td>Low Vulnerability, Low Impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kalakaua Avenue</td>
<td>Low Vulnerability, Low Impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>McCully Street</td>
<td>Low Vulnerability, Low Impact</td>
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<table>
<thead>
<tr>
<th>Risk Level in Year 2100</th>
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<th>Vulnerability</th>
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<tbody>
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<tr>
<td>Kalakaua Avenue</td>
<td>Low Vulnerability, Low Impact</td>
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</tr>
<tr>
<td>McCully Street</td>
<td>Low Vulnerability, Low Impact</td>
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</tbody>
</table>

Reasons & Discussion

Wind velocity during storm events is predicted to increase 12.5% by 2050 over 2000 level and 25% by 2100.

Wind was determined not to be a climate change variable affecting any of the bridges due to the generally low profile and concrete construction of the bridges and each bridge was given a low vulnerability and impact rating in the years 2050 and 2100.

D. High Intensity Rainfall

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Bridge Name</th>
<th>Vulnerability</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ala Moana Boulevard</td>
<td>Low Vulnerability, Low Structural Impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kalakaua Avenue</td>
<td>Moderate Vulnerability, Moderate Structural Impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>McCully Street</td>
<td>Moderate-High Vulnerability, Moderate-High Structural Impact</td>
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</table>

<table>
<thead>
<tr>
<th>Risk Level in Year 2100</th>
<th>Bridge Name</th>
<th>Vulnerability</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ala Moana Boulevard</td>
<td>High Vulnerability, High Structural Impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kalakaua Avenue</td>
<td>High Vulnerability, High Structural Impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>McCully Street</td>
<td>High Vulnerability, High Structural Impact</td>
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</tbody>
</table>

Reasons & Discussion

Currently, during heavy storm water runoff, the Ala Wai Canal water surface rises, and street drains cannot effectively discharge into the Ala Wai. This causes flooding at the manholes and the street drains along the Ala Wai Canal, leaving standing water on adjacent Ala Wai Boulevard and its sidewalks as well as those along Hobron Lane. With sea level rise, this problem will happen not only during heavy rains, but every day during high tide, much like in the Mapunapuna area discussed in Section 3.

While precipitation is predicted to decrease by 18% by 2050, the intensity of rainfall is predicted to increase. Increased precipitation intensity would probably increase the short-term stream volume discharges, which may contain higher sediment loads and greater volume of debris as a result of flash-flood type of runoff. The potentially higher sediment loads and larger volumes of debris could clog the Ala Wai Canal or create floating obstructions at the bridges, which all have relatively low height decks and low water surface clearance. This, coupled with the sea level rise, will increase the risk level by 2100 for all three bridges to high vulnerability, high impact.
E. Air Temperature

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Bridge Name</th>
<th>Vulnerability &amp; Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ala Moana Boulevard Bridge</td>
<td>Low Vulnerability, Low Structural Impact</td>
<td></td>
</tr>
<tr>
<td>Kalakaua Avenue Bridge</td>
<td>Low Vulnerability, Low Structural Impact</td>
<td></td>
</tr>
<tr>
<td>McCully Street Bridge</td>
<td>Low Vulnerability, Low Structural Impact</td>
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</table>

<table>
<thead>
<tr>
<th>Risk Level in Year 2100</th>
<th>Bridge Name</th>
<th>Vulnerability &amp; Impact</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Low Vulnerability, Low Structural Impact</td>
<td></td>
</tr>
<tr>
<td>Kalakaua Avenue Bridge</td>
<td>Low Vulnerability, Low Structural Impact</td>
<td></td>
</tr>
<tr>
<td>McCully Street Bridge</td>
<td>Low Vulnerability, Low Structural Impact</td>
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</tr>
</tbody>
</table>

Reasons & Discussion

Air temperature is predicted to rise by $0.16^\circ F$ per decade.

For the purposes of this risk assessment, air temperature was determined not to be a climate change variable affecting any of the bridges, and each bridge was given a low vulnerability and impact rating in the years 2050 and 2100.

5.4 Integrated Risk Assessment

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Bridge Name</th>
<th>Risk Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ala Moana Boulevard Bridge</td>
<td>MODERATE</td>
<td></td>
</tr>
<tr>
<td>Kalakaua Avenue Bridge</td>
<td>MODERATE</td>
<td></td>
</tr>
<tr>
<td>McCully Street Bridge</td>
<td>MODERATE</td>
<td></td>
</tr>
<tr>
<td>Combined Risk Integrated Score for All Three Bridges</td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Level in Year 2100</th>
<th>Bridge Name</th>
<th>Risk Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ala Moana Boulevard Bridge</td>
<td>HIGH</td>
<td></td>
</tr>
<tr>
<td>Kalakaua Avenue Bridge</td>
<td>HIGH</td>
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<tr>
<td>McCully Street Bridge</td>
<td>HIGH</td>
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</tr>
<tr>
<td>Combined Risk Integrated Score for All Three Bridges</td>
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<td></td>
</tr>
</tbody>
</table>

Reasons & Discussion

The team concluded that of the three bridges, McCully Street Bridge is the least vulnerable to storm surge and sea level rise because of its location furthest away from the ocean. But because of the major utilities, in some ways, McCully Street Bridge is the most important bridge. Ala Moana Boulevard Bridge, being nearest to the open ocean, is the most vulnerable to storm surge and sea level rise.

Sea level rise and high intensity rains coupled with current daily drainage issues and the low elevation to pass beneath the bridges all elevated the bridges’ risk levels in 2100. The bridges may be inaccessible due to sea level rise, and even their nearby sidewalks may be impassable because the Ala Wai Canal may spill over its banks.
5.5 Data Sources

Hawaii Department of Transportation Highways Division. NBI Bridge Inspection Report for Ala Moana Boulevard Bridge. 2009.
Sea Level Modeling by University of Hawaii Coastal Geology Group, C. Fletcher and M. Barbee. 2011.
Section 6.0 Risk Assessment of Rt-93, Farrington Highway – Access and System Redundancy

Asset Group: Farrington Highway – Access and System Redundancy

Facility Named in this Asset: Rt-93, Farrington Highway

6.1 Asset Description

Rt-93, Farrington Highway on the Waianae Coast is approximately 18 miles in length between Waimanalo Gulch and Yokohama Bay. The highway hugs the Leeward Coast of Oahu and is the only ingress and egress for the communities on the Leeward Coast. From Nanakuli to Makaha Valley Road, the highway is two lanes wide in both directions, but for the remaining ten miles, it is a two lane highway. Bi-directional traffic is not separated by any barriers, except for a short section between Hakimo and Kaukama roads. There are no improved sidewalks except for a limited area near the business center of Waianae Mall. According to the Waianae Sustainable Communities Plan, there are 27 signalized intersections between Nanakuli Avenue and Makaha Valley Road, which is just eight miles long, but this is where the majority of residences are located.

This transportation asset includes main cross streets/access points to the Waianae Coast of:

- Nanakuli Avenue
- Haleakala Avenue
- Hakimo Road
- Leihoku Street
- Lualualei Homestead Road
- Waianae Valley Road
This transportation asset includes 16 stream and gulch crossings as shown in Figure 34:

- Waimanalo Gulch
- Kahe Stream
- Limaloa Gulch
- Nanakuli Stream
- Ulehawa Stream
- Maipalaoa Stream
- Mailiili Stream
- Kawiwi/Kaupuni Stream
- Makaha Stream crosses twice
- Keaau Stream
- Waikomo Stream
- Kalahai Gulch
- Makua Stream
- Punapohaku Stream
- Kaluakauila Stream

![Figure 34: Main Streets and Streams Crossings, Farrington Highway, Waianae Coast](image)

This coastline is made up of nine different ahupua‘a as shown in Figure 35:

- Nanakuli
- Lualualei
- Waianaes
- Makaha
- Keaau
- Ohikilolo
- Makua
- Kahanahaiki
- Keawaula
The ahupua’a is a traditional unit of land division in Hawaii, extending from the ocean to the upper mountain slopes. Occupants of an ahupua’a had access to resources from both the ocean and the forest as a sustainable system of resource sharing and management. As seen in Figure 35, the ahupua’a division follows the streams as a water resource. Noting the ahupua’a is important given that, according to US Census Data from 2010, more than half of the Waianae Coast population identifies itself as Hawaiian or part-Hawaiian.

### 6.2 Importance of the Asset to Society

<table>
<thead>
<tr>
<th>Societal Value of Asset</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of Use</td>
<td>HIGH</td>
</tr>
<tr>
<td>Degree of Redundancy</td>
<td>LOW</td>
</tr>
<tr>
<td>Cost to Replace</td>
<td>HIGH</td>
</tr>
<tr>
<td>Economic Loss</td>
<td>HIGH</td>
</tr>
<tr>
<td>Environmental Impacts</td>
<td>MODERATE</td>
</tr>
<tr>
<td>Cultural Value</td>
<td>MODERATE</td>
</tr>
<tr>
<td>Loss of Life</td>
<td>MODERATE-HIGH</td>
</tr>
<tr>
<td>Recovery Time Needed</td>
<td>HIGH</td>
</tr>
</tbody>
</table>
Rt-93, Farrington Highway along the Waianae Coast represents the only publicly-available ingress and egress for the entire coast. While certain subsections of Farrington Highway offer an alternate route from the ocean to the valley roads, at Kahe Point there is no alternate route leading out of the region. The military does control access through Kolekole Pass near Lualualei Homestead Road, but this only provides limited access for military vehicles and is not open to the public.

If any part of Rt-93, Farrington Highway becomes impassable, entire communities or even the entire Waianae Coast could be shut off from the rest of the island. In the past, closures have been caused by utility poles falling, critical traffic accidents, domestic violence standoffs, and flooding from storm surge or heavy rains.

Rt-93, Farrington Highway encompasses five Census Demographic Profiles (CDP) with the following populations according to the 2010 Census and shown on the map in Figure 36:

- Nanakuli CDP: 12,666
- Maili CDP: 9,488
- Waianae CDP: 13,177
- Makaha CDP: 8,278
- Makaha Valley CDP: 1,341
- Total: 44,950

The Census also shows that one-third of the residents are either over 65 or under 18, which gives special considerations for transportation planners when considering evacuation routes. Many residents live at or below the poverty line, making this an especially vulnerable population, and there are large concentrations of homeless.

**Figure 36: Census Demographic Profiles (CDP), Waianae Coast**
Commercial activity occurs along the entire route. According to the Draft Waianae Sustainable Communities Plan Update (2011), the designated business districts along the Leeward Coast include Waianae Town Center and Nanakuli Village Center. The community did not wish to establish additional town, village, or community centers. This means that the majority of the residents need to commute elsewhere on the island for employment.

During storm surge resulting from a storm event, it would make sense to evacuate the population towards the mountains. However, as seen in the GIS Map (Figure 33, above), many of the evacuation shelters are in close proximity to the ocean, such as in Makaha. Makua and Nanakuli are two areas of the Waianae Coast that do not have any upland evacuation alternative since the base of the mountain is at the ocean. These areas are between three and fifteen feet in elevation, which could be underwater with storm surge and the swelling of streams.

There is no redundancy for this large and somewhat vulnerable population base. As discussed earlier in this section, portions of Rt-93, Farrington Highway are undercut by the ocean. To replace one lane mile would conservatively cost $6.5 million. With eight miles at four lanes and ten miles two lanes, it would cost at least $260 million to rebuild Rt-93, Farrington Highway. If the highway were to be cut off from the rest of Oahu close to Nanakuli, this would leave nearly 50,000 people without access to fuel, food, and major medical care. For these reasons, the team ranked this as a high value asset.

### 6.3 Risk Assessment for Rt-93, Farrington Highway

#### A. Sea Level Rise:

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Moderate-High Vulnerability, High Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>High Vulnerability, High Structural Impact</td>
</tr>
</tbody>
</table>

**Reasons & Discussion**

Active shoreline erosion is found near Yokohama Bay, where erosion and loss of land are undercutting localized portions of Rt-93, Farrington Highway. With sea level rise, this will only exacerbate the current situation, leading to potential roadway damage in affected areas, and potentially cutting communities off from the rest of the island.

#### B. Storm Surge:

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>High Vulnerability, High Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>High Vulnerability, High Structural Impact</td>
</tr>
</tbody>
</table>

**Reasons & Discussion**

In multiple sections along Rt-93, Farrington Highway, when there is no physical barrier between the existing highway and the ocean, wave overtopping events during large winter storms have been documented. This has caused localized flooding of the highway, making passage difficult during storm events. Many of these locations coincide with stream and gulch crossings beneath Farrington Highway. Add to this current condition the predicted sea level rise and a predicted 15-30% increase in tropical storms by 2050, the problem will only worsen by 2100. For this reason, the risk level was ranked high for both years.

While storm surge maps do not exist for the Waianae Coast, the team used the Sea Level Rise model to identify low lying areas that may be susceptible to storm surge.
C. Wind

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Moderate Vulnerability, Moderate Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>High Vulnerability, High Structural Impact</td>
</tr>
</tbody>
</table>

Reasons & Discussion

Power lines and transmission poles in this area are above ground and are susceptible to falling across the highway during high winds. Traffic signals use cantilevered mast arms, which span over Rt-93, Farrington Highway at existing signalized intersections. These can also topple during high winds.

When the strong southwesterly winds are blowing, locally referred to as “Kona Winds,” as opposed to the prevailing northeasterly “Tradewinds,” there is an increase in shoreline wave overtopping and wave set-up, especially during high tides. Kona Winds normally blow during the winter season and they are rain-bearing.¹³

Storm frequency is predicted to increase 15-30% by 2050, and could increase by as much as 30-60% by 2100. Any storms that are accompanied by high winds increase this asset’s vulnerability.

D. High Intensity Rainfall and Drought

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Drought</th>
<th>High Vulnerability, High Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainfall</td>
<td>Moderate Vulnerability, Moderate Structural Impact</td>
</tr>
<tr>
<td>Risk Level in Year 2100</td>
<td>Drought</td>
<td>High Vulnerability, High Structural Impact</td>
</tr>
<tr>
<td></td>
<td>Rainfall</td>
<td>High Vulnerability, High Structural Impact</td>
</tr>
</tbody>
</table>

Reasons & Discussion

There are 16 stream and gulch crossings along this portion of Farrington Highway. With the predicted increase in precipitation event intensity, bridge and culvert scour may become a problem as well as the blockage of culverts from upstream debris.

On the opposite end of the spectrum, this area is also susceptible to drought. The highest recorded temperature on the island of Oahu was in Waianae during July 1915 at 98°F. This coupled with low rainfall leads to dry conditions, making the area prime for brushfires. The entire island of Oahu was declared to be in drought conditions for 2000-2002, 2004, and 2007, and part of 2010, and there is a prediction of 18% less precipitation statewide by 2050. These dry conditions could cause increased slope instability when a period of drought is followed by a period of high intensity or prolonged heavy rainfall. Two slope hazard areas were noted near Nanakuli and also near the Makua Cave at the opposite end of the highway.

Note that this is the only asset where the team separated drought conditions from increased rainfall intensity. The leeward side of the island, which – in terms of an island’s weather system – is always drier than the windward side, includes the entire Waianae Coast. The Waianae Coast receives the least amount of rainfall as shown in both Table 2 and Figure 6 of Section 1.0. The team had decided through the course of discussion on the other

transportation assets to concentrate on just increased rainfall intensity and note the absence of rainfall when necessary.

### E. Air Temperature

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>Low Vulnerability, Low Structural Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>Low Vulnerability, Low Structural Impact</td>
</tr>
</tbody>
</table>

**Reasons & Discussion**

As noted above, the highest recorded Oahu temperature was in Waianae during July 1915 at 98°F. The average high temperature for Waianae is 82.6°F. While the air temperature is rising at 0.16°F per decade, with a predicted increase of 1.6°F by 2100 from 2000 levels, the air temperature was not deemed to have any significant effect on this transportation asset over time.

### 6.4 Integrated Risk Assessment

<table>
<thead>
<tr>
<th>Risk Level in Year 2050</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level in Year 2100</td>
<td>HIGH</td>
</tr>
</tbody>
</table>

**Reasons & Discussion**

If the eye of a strong hurricane hits the island of Kauai or passes between Kauai and Oahu (as Hurricanes Iwa and Iniki did), the Waianae Coast would be within the upper right quadrant of the hurricane wind circulation. This means the storm surge and winds would potentially be strongest on the Waianae Coast. Hurricanes Dot (1959), Iwa (1982) and Iniki (1992) were the only hurricanes to make landfall in the last 50 years, and all three hit Kauai and resulted in damage to the Waianae Coast.

Portions of Rt-93, Farrington Highway are experiencing erosion undercutting the road, and this will only become more pronounced over time due to sea level rise and storm surge. Figure 37 shows a rock retaining wall built below Farrington Highway, blended in with the landscape.
The 16 stream and gulch crossings are susceptible to bridge scour, erosion of stream banks beneath highway, and the potential for debris to become trapped at these crossings and cause flooding upstream. Figure 38 shows one of these stream crossings.

This risk assessment score remained at high once integrated with the socioeconomic risk assessment.
6.5 Data Sources

City & County of Honolulu, Department of Planning and Permitting. 2011 Waianae Sustainable Communities Plan (DRAFT) Update to 2000 Waianae Sustainable Communities Plan.
Sea Level Modeling by University of Hawaii Coastal Geology Group, C. Fletcher and M. Barbee. 2011.
Section 7.0 Summary of Integrated Matrix

The project team selected two planning horizons of 2050 and 2100 for this project, with a baseline of 1970 to 2000. The planning horizons were to give transportation planners time to adapt the transportation assets, while also showing the acceleration of climate change effects in the last half of the century, from 2050 to 2100. The baseline of 1970 to 2000 was selected so that the base measurements would have an historical perspective and the ability to display baseline trends. These definitions were all based on available information from peer-reviewed literature.

During the first group work session, which took place over two days, the transportation assets were first ranked for a level of vulnerability and a level of structural impact, for both years 2050 and 2100. The ranking levels available for use by the team were: high, medium, and low. The team reviewed each of the five transportation asset groups and performed a vulnerability assessment to look at the likelihood of future climate changes and the magnitude of future climate changes.

The next group work session looked at the social and economic consequences to society. It was not possible to conduct a full economic valuation of each asset. Therefore, in determining how valuable an asset might be, the following list was considered in the aggregate:

Ways to Value an Asset
- Level of use
- Use of asset for evacuation, civil defense activities, and emergency functions
- Degree of redundancy
- Cost to replace
- Economic loss
- Environmental impacts
- Cultural value
- Loss of life
- Recovery time needed

The team agreed to use a three-tier low, medium, high ranking system to classify integrated risk vulnerability. These measurements considered the three climate change factors that presented the highest vulnerability and had the greatest likelihood of occurrence: sea level rise, storm surge, and high intensity rainfall. These three ranking categories are:
- Low Ranking: Repair of asset needed, but can work around it
- Medium Ranking: Asset is temporarily unusable and in need of repair
- High Ranking: Total catastrophic loss

Once the consequences to society were determined, the team assigned an integrated risk score to each of the five asset groups. The integrated risk combined scores for vulnerability, impact, and consequences to society, using the two planning horizons years of 2050 and 2100.

The integrated risk score was not achieved by a simple formula. For example, an asset could have a low risk of vulnerability and impact to its infrastructure, but the effect on society could be devastating. This is illustrated with the vulnerability and impact rankings in the year 2050 for Honolulu Harbor, which are both low. In this report, the discussion on the value of Honolulu Harbor to the state of Hawaii shows how dependent the state is on the shipping industry for its goods, food, and fuel. Therefore, while sea level rise would only have a low vulnerability and low impact in the year 2050 to the piers, gantry cranes, and other physical structures of Honolulu Harbor, the team had to give this asset a high integrated risk ranking.
It should also be noted that the transportation assets were selected in the March Workshop with OahuMPO, FHWA, and ICF present to help guide the stakeholders in their transportation asset selection. Because this was a pilot project, the scope could not afford a study of all transportation assets on the island of Oahu. It makes sense that the March Workshop attendees selected assets with a high value to society, and in the end, all assets were ranked moderate or high when integrating risk with societal value.

Table 5 shows the risk assessment for each transportation asset group. Table 6 shows the importance of the asset group to society. Table 7 gives the integrated risk assessment for each of the transportation asset groups.

### Table 5: Risk Assessment

<table>
<thead>
<tr>
<th>Asset</th>
<th>Period</th>
<th>Sea Level Rise</th>
<th>Storm Surge</th>
<th>High Intensity Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Vulnerability</td>
<td>Impact</td>
<td>Vulnerability</td>
</tr>
<tr>
<td>Honolulu Harbor</td>
<td>2050</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>2100</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Honolulu International Airport</td>
<td>2050</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>TheBus (811 Middle Street)</td>
<td></td>
<td>Low-Moderate</td>
<td>Low-Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Oahu Baseyard (727 Kakoi Street)</td>
<td>2050</td>
<td>Low-Moderate</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>2100</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Honolulu International Airport and Access</td>
<td>2050</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>2100</td>
<td>Low-Moderate</td>
<td>Low-Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Kalaeloa Barbers Point</td>
<td>2050</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>2100</td>
<td>Low-Moderate</td>
<td>Low-Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Three Waikiki Bridges</td>
<td>2050</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Ala Moana Boulevard</td>
<td></td>
<td>Low-Moderate</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Kalakaua Avenue</td>
<td>2050</td>
<td>Moderate</td>
<td>Moderate-High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>2100</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>McCully Street</td>
<td>2050</td>
<td>Low-Moderate</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>2100</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Farrington Highway on Waianae Coast</td>
<td>2050</td>
<td>Moderate-High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
### Table 6: Importance of the Asset Group to Society

<table>
<thead>
<tr>
<th>Asset</th>
<th>Overall Value</th>
<th>Storm Surge</th>
<th>Sea Level Rise</th>
<th>Heavy Rain/Storm Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honolulu Harbor</td>
<td></td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Honolulu International Airport</td>
<td></td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>TheBus (811 Middle Street)</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Oahu Baseyard (727 Kakoi Street)</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Honolulu International Airport and Access</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

### Table 7: Integrated Risk Assessment

<table>
<thead>
<tr>
<th>Asset</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honolulu Harbor</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Honolulu International Airport</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>TheBus (811 Middle Street)</td>
<td>Low-Moderate</td>
<td>Moderate-High</td>
</tr>
<tr>
<td>Oahu Baseyard (727 Kakoi Street)</td>
<td>Moderate-High</td>
<td>Moderate-High</td>
</tr>
<tr>
<td>Honolulu International Airport and Access</td>
<td>Low-Moderate</td>
<td>Low-Moderate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kalaeloa Barbers Point</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalaeloa Airport</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Campbell Industrial Park</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Kalaeloa Barbers Point Harbor</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Access Roads</td>
<td>Low</td>
<td>Low-Moderate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Three Waikiki Bridges</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ala Moana Boulevard Bridge</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Kalakaua Avenue Bridge</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>McCully Street Bridge</td>
<td>Moderate</td>
<td>High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Farrington Highway on Waianae Coast</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
Section 8.0 Lessons Learned and Recommendations

The evaluation of the transportation assets and their vulnerability to climate change provided an opportunity to bring together multi-disciplinary professionals. The project team included climate scientists, planners, and engineers, all of whom had extensive knowledge and experience in planning, designing, and building Oahu’s transportation infrastructure, and were able to “localize” climate forecasts to Hawaii and Oceania.

A “triage” approach was determined to most effectively meet the project goals within the constraints of budget and time. The pilot grant amount received by OahuMPO was $85,000. The local match consisted of in-kind contributions, making the amount available for the vulnerability assessment by the consultant only $53,000. The primary benefit of the multi-disciplinary approach was to serve the stated goal of developing a process that would be easily replicable and transferrable to not only Oahu’s neighboring islands in Hawaii but to the Pacific island nations in general. Climate change risk assessments for other islands and territories may be assumed to be done under very tight financial constraints.

This section discusses lessons learned based on applying the FHWA Model for the pilot study as shown in Figure 1. The comments in this section are offered to help improve the model and future applications.

8.1 Approach to the Project

The three primary components to the project were designed to:

1. Develop an understanding of the climate science applicable to Hawaii. Both the University of Hawaii’s School of Ocean and Earth Science and Technology (SOEST) and the Hawaii office of the National Oceanic and Atmospheric Administration (NOAA) were well prepared to provide technical guidance concerning the application of climate trends to Oahu. This included the development of LiDAR-based inundation maps for the areas of the island where vulnerable assets were located as well as estimates for the impacts of climate change in 2050 and 2100 given a historic baseline of 1970-2007.

2. Identify the priority transportation infrastructure. This was accomplished during a two-day workshop that is discussed in detail in Section 1. Bringing together the key management and staff charged with planning, designing, engineering, and operating all modes of transportation on Oahu was the most efficient way of both identifying and prioritizing the infrastructure. While the first morning of the workshop was devoted to giving participants an overview of what to anticipate from a climate science perspective, the remainder of the workshop focused exclusively on the identifying of assets vulnerable to those climate changes and prioritizing them. The climate change risk assessment consultant had to further define each transportation asset and its components in order to conduct the assessment.

3. Conduct a vulnerability risk assessment determining the impact of climate change factors on the priority assets. OahuMPO contracted with SSFM International, Inc., to conduct the analyses of the impacts of the climate change factors of rainfall, sea level rise, and more frequent storms of greater intensity on the five transportation assets deemed to be the most vulnerable and of the highest priority. Some of these assets may be best characterized as “regions” of assets. The climate change risk assessment consultant had to determine definitions and scales to apply to the assessment work.
8.2 Discussion of Issues Related to the Approach

While the workshop accomplished the goal of defining and prioritizing the assets, there were issues with ensuring that the persons who attended were the most appropriate to contribute to a successful outcome. There were two reasons for this. The importance of climate change is not something on which the heads of some agencies are focused. One commented, for example, that climate change is an issue that will need to be faced “seven mayors from now.” Another questioned the validity of the science underlying climate change forecasts. It took time in getting agreement and ensuring that the value of this effort was recognized.

It would have been preferable for OahuMPO to have had the benefit of an up-front local match in order to maximize the amount of funding that would have been available. This would also have allowed a consultant to have been retained prior to the workshop and made the synthesis of all aspects of the analyses easier, especially as the final report was being drafted.

For purposes of simplicity as well as recognizing the budgetary constraints, OahuMPO and its consultant agreed on a ranking of vulnerability as “high,” “moderate,” or “low” as defined in the FHWA model. However, the consulting team agreed that more ranking categories were necessary. Five categories would have been more accurate for the risk assessment, and this report does show some hybrid ranking such as “low-medium.” This would also give a more accurate measure for transportation planners to create a project prioritization list.

A good assessment needs good data. A considerable amount of time was spent by the consulting team to clearly define the transportation assets. This tied back to the reliance on the planning and engineering managers and staff for defining the assets. In all cases each vulnerable asset consisted of multiple “sub-assets.” This made it necessary to make assumptions about their individual contribution to the overall value to the asset – both from a societal as well as structural aspect.

Similarly, the climate change variables required more detailed definition than had been provided at the workshop. The consulting team needed to set baseline measurements for the climate change variables, as well as selecting future years to apply the risk assessment. The climate change information provided to the planners and engineers at the workshop was at a more general level than that needed for the vulnerability risk assessment.

Most resource agencies were willing to provide the information that was requested when it was available. From the NOAA office in Honolulu to the Port of New Orleans, once it was explained why the information was needed, people were willing to research and point the research team in the direction of reports. This reflects a high interest in the topic of climate change.

The team members individually found sources for much of the data used in this risk assessment. It was valuable to have the University of Hawaii SOEST sea level rise model authors as part of the team making scientifically verifiable assumptions about sea level rise. It would have been helpful to have wind models for all parts of the island. It would have been even more useful to have different models integrated, such as being able to assume a certain height of sea level against a certain category of hurricane.

Some specialty data were available to the team members only due to their professional work and affiliations. Thus, multi-disciplinary areas of expertise proved crucial to this project. The consultant project team included a licensed geologist who was very familiar with the geography of the island, two engineers, two landscape architects who possessed expertise with Native Hawaiian plants, and a planner, all of whom regularly practice in Hawaii.

Participants agreed that the project strategy benefitted from “having the right people in the room.” The team was assembled as a group of scientists, engineers, and planners; all considered subject matter experts in their respective disciplines. The team of professionals worked well together. Everyone was respectful of the time
allotted to the exercise and respectful of one another’s time. The agenda functioned as the clock for assessing each transportation asset, and each participant respected the agenda so that all could get through the material on time.

Recording all the data live on large sheets and posting them around the room helped keep the team on track as well as make information readily available. All could find their place easily for each of the transportation assets because the data, assumptions, and discussions were written out for each team member to see.

It was helpful and much appreciated to have the participation of Oahu Transit Services (OTS), operators of TheBus and TheHandi-Van, being willing to participate during part of the climate change variable assessment when discussing their transportation assets. OTS was able to validate assumptions as well as provide additional information to give the team a multi-dimensional view of how the asset functioned.

When the asset owner/operator could not attend the risk assessment, second best was having a conference call during the exercise. It was much appreciated to have the input of Frank Doyle from the City and County of Honolulu’s Department of Environmental Services answering historical questions Sand Island Wastewater Treatment Plant in Honolulu Harbor and H-POWER in Kalaaeloa. It was much appreciated to also have the input of Steve Kelly from Kapolei Property Development to give additional perspectives on Campbell Industrial Park.

### 8.3 Recommendations to Improve the Approach

It would be helpful to consult with disaster response and disaster planning agencies. Examples are State Civil Defense, branches of the U.S. military, and the City’s emergency responders. Their perspectives would be helpful when discussing issues like evacuating an isolated community or an area with lots of visitors. While State Civil Defense and the Honolulu Department of Emergency Management participated in the agency workshop, they were not part of the risk assessment sessions.

Lessons learned from cities that have experienced the climate change or extreme weather events were very helpful. Learning from their experiences was valuable to transportation planners as they tailored their projects for their specific environments. Ms. Elizabeth Fischer of Federal Highway Administration provided an overview of other parts of Oceania that are already experiencing climate change in more dramatic ways than Hawaii. While the consulting team had that presentation as a PowerPoint, it did not benefit from the discussion of impacts and adaptation strategies other Pacific island nations are using.

Lessons learned from major disasters elsewhere also helped to inform the consultant project team when discussing the value of a transportation asset to society. For example, the project team had information regarding how long it took Sendai Airport in Japan to become operational for emergency supplies and then later commercial flights, and this was useful during the discussion of Honolulu International Airport. Local knowledge and discussions on Hurricanes Iwa and Iniki and their effects on Kauai and the Waianae Coast of Oahu also helped the team when discussing the Farrington Highway asset. While these disasters were not specifically related to climate change, their effects on the transportation assets and society were similar to those from climate change.

A trained facilitator can assist in the brainstorming effort, and this is especially helpful when a large group is assembled. For the March Climate Change workshop, professional facilitators were used for each of the breakout sessions as well as the final plenary session. The vulnerability risk assessment sessions were done with a smaller working group, and the consultant team was able to provide its own resources for facilitation.
8.4 Data Gaps for Improved Future Risk Assessment

There is an immediate and significant need to develop downscaled, Hawaii-specific model projections for the following climate change variables:

- Local wind
- Local rainfall
- Localized storm and hurricane wind speed
- Stream flood projections under the combined conditions of higher sea level rise and increased rain intensity

Similarly, more information about both the potential impacts of climate change is required from both socioeconomic and societal perspectives. The identification and prioritization of assets was based on a best professional judgment consensus developed by the workshop participants and consultant team. More data related to the cost of replacement, time to replace, and other asset-specific variables would have been useful. In addition, while the impact to a structure, for example, may be low under a certain circumstance, the loss of its use for even a short period could be catastrophic to society or Oahu’s economy. It was evident that future assessments would benefit from much more robust datasets across both climate change and transportation asset categories.

8.5 Other Recommendations

While this project was to be a general assessment to confirm the validity of the conceptual model, it would be helpful to transportation planners and engineers to have a more in depth assessment in order to prioritize their projects. Part of the reason the assessment was kept general was because of the short time constraints for the pilot, and the other reason was because of the limited funding. Like most things, more time and more money would have enhanced the project.

A crisp definition of the transportation asset is necessary in order to perform an accurate assessment and projection. A considerable amount of time was spent breaking down each of the five transportation asset areas in order to make them more manageable for this project.

All assumptions need to be documented, including definitions of transportation assets, climate change variables, and socioeconomic variables. This will help when building the exercise to maintain consistent ranking when comparing amongst all assets.

The risk assessment was done in two separate parts. The first risk assessment was done to determine the risk and impact to the physical transportation infrastructure. The second risk assessment involved the consultant team evaluating the societal value of the asset. The integrated risk assessment then included how the impact of climate change on the asset could affect both the physical transportation asset and the value to society.

To maintain the flexibility and adaptability of the model, it may not be desirable to define precisely how societal value should be incorporated into the evaluation methodology, but it may be desirable to provide a few different examples of how it can be incorporated, and to further stress that it should be incorporated into the evaluation.
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Appendix A

Oahu Metropolitan Planning Organization:
Planning for Climate Change
The Climate Change & Transport Data Model

Oahu Metropolitan Planning Organization
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Honolulu, HI 96813
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E-mail: Brian.Gibson@OahuMPO.org

The Climate Change & Transport Data Model

The Oahu Metropolitan Planning Organization (OahuMPO) is responsible for coordinating transportation planning on Oahu. Federal law mandates that metropolitan planning organizations (MPOs) ensure that existing and future expenditures for transportation projects and programs are based on a comprehensive, cooperative, and continuing (3-C) planning process. Federal funding for transportation is channeled through this 3-C process.

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Thank you for participating in the Climate Change Workshop, scheduled for March 8 and 9 at the East-West Center on the University of Hawaii at Manoa campus. We are providing you with information that will help you get the most out of the event.

Please read this document for the workshop’s background. We ask you to complete this series of short exercises prior to arriving. Bring your completed exercises and this flyer with you to the conference.

There are three main goals for the workshop to:
1) Identify and discuss key climate stressors for the future,
2) Identify and prioritize important transportation assets that may be at risk to the impacts of climate variability, and
3) Identify sources of important data for those high-priority transportation assets.

Following the conference, OahuMPO will retain a consultant to refine workshop outcomes by assessing the prioritized transportation assets and how vulnerable they may be to future climate variability. Identifying these vulnerabilities now is an important step toward deciding how best to mitigate the potential impacts of climate change, and gives Oahu’s transportation planners and engineers more time and opportunity to implement mitigation measures than would be available if we wait until the climate stressors become a “problem.”

Your participation in this process is a vital component of this important transportation planning work.

The Climate Change & Transport Data Model

The workshop will focus on three climate stressors:
1) Sea-level rise
Consensus among climate scientists appears to be coalescing around a future sea level that is about three feet higher than it is today. Llow-lying coastal infrastructure will be particularly at risk from higher tides and tidal surges.

2) Flooding
Hawaii will likely receive less total rainfall, and drought may be more common. However, rainfall events, when they do occur, are likely to be significantly heavier than they are today. The drought-heavy rainfall cycles may result in loss of critical vegetation that supports hillsides and embankments. More flooding will occur.

3) Increased storm frequency and intensity
Tropical storms and even hurricanes may occur over Hawaii more frequently than they have in the recent past. It is expected that storm events will become more intense. Sea-level rise will likely increase the impacts.

The Climate Change Data Model

Inventory of Assets
- Develop inventory of assets
- How important is each asset?
- Risk

Climate Information
- What is the likelihood and magnitude of future climate changes?
- What is the likelihood and magnitude of future climate changes?

Planning for Climate Variability

Points of interest:
- Pacific island nations are already feeling the effects of various climate stressors.
- In 2006, Oahu had 44 days of rain and the effects of flooding and landslides had a great impact on highway infrastructure.
- The past decade was the warmest in recorded history.
- Unlike many small, developing island nations, as part of the United States, Hawaii has the capacity and resources to mount a credible defense against environmental impacts caused by climate change.
Imagine the Impacts of Sea-Level Rise

If the average sea-level were to rise by three feet over the next couple of decades, what would be your biggest concerns in terms of transportation assets and operations?

With which roadways, corridors, and/or bridges would you be most concerned about?

1)_________________________________  2)_________________________________  3)_________________________________  4)_________________________________  5)_________________________________

With which airport and/or harbor functions or operations would you be most concerned?

1)_________________________________  2)_________________________________  3)_________________________________  4)_________________________________  5)_________________________________

Shoreline will reach Moiliili assuming a one meter sea-level rise. Photo courtesy of the Blue Line Project.

Landslides will present significant hazards, especially if heavy rains follow extended periods of drought. Photo courtesy of Kalani Lancaster.

Imagine the Impacts of Severe Storms

Tropical storms and hurricanes may occur in Hawaii more frequently in the future than they have in the past. It is anticipated that the severity of storms will increase as a result of climate variability. Not only would high winds and heavy rainfall be a concern but storm surge would be a major factor, especially if sea-level rises.

A 2009 exercise conducted by the Federal Emergency Management Agency with other Federal, State, and City participants estimated that a category four hurricane making landfall at Ewa would result in substantial damage to all forms of transportation infrastructure on Oahu.

With which roadways, corridors, and/or bridges would you be most concerned, recognizing that most of Oahu’s airports and harbors (military & civilian) are along the shoreline?

1)_________________________________  2)_________________________________  3)_________________________________  4)_________________________________  5)_________________________________

Hurricane Iniki caused $2.5 billion dollars of damage and six deaths in 1992, affecting both Oahu and Kauai. Picture courtesy of Wikipedia Commons.

Finding the Key Characteristics and Data

If you work with airports or harbors, which functions or operations would you be most concerned about?

1)_________________________________  2)_________________________________  3)_________________________________  4)_________________________________  5)_________________________________

If you work with roadways, corridors, and/or bridges, which functions or operations would you be most concerned about?

1)_________________________________  2)_________________________________  3)_________________________________  4)_________________________________  5)_________________________________

If Oahu was experiencing severe flood conditions, what would your biggest concerns be?

1)_________________________________  2)_________________________________  3)_________________________________  4)_________________________________  5)_________________________________

A heavy rainfall event can result in flooding (sometimes from culverts and bridges being blocked with debris, erosion, rock falls, and scour around bridgeheads and footings).

Identify any areas that you are aware of having a history of flooding or landslides.

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Finally, look back at the answers that you provided in the three previous exercises. What key characteristics of those assets most concern you? For example, when imagining sea-level rise, you might be most concerned about the physical elevation of the asset (i.e., how far above present sea-level is it?). When thinking about heavy rainfall, you might be most concerned about the size of a culvert or the slope of a ditch. In the space provided, please identify where we might find the relevant data for the assets you identified as well as the format in which those data are available (e.g., ESRI, Intergraph, or other; if other, please list).

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If the average sea-level were to rise by three feet over the next couple of decades, what would be your biggest concerns in terms of transportation assets and operations?

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Points of interest
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• In 2006, Oahu had 44 days of rain and the effects of flooding and landslides had a great impact on highway infrastructure
• The past decade was the warmest in recorded history
• Unlike many small, developing island nations, as part of the United States, Hawaii has the capacity and resources to mount a credible defense against environmental impacts caused by climate change

The future of Hawaii’s climate

The workshop will focus on three climate stressors:
1) Sea-level rise
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3) Increased storm frequency and intensity
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Appendix B
March 8 and 9, 2011
Climate Change Workshop Attendees
<table>
<thead>
<tr>
<th>First Name</th>
<th>Last Name</th>
<th>Agency/Organization</th>
<th>Title</th>
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<tr>
<td>A. Ricardo</td>
<td>Achilla</td>
<td>University of Hawaii-Department of Civil Engineering</td>
<td>Associate Professor</td>
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<td>Susan</td>
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<td>Manager</td>
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<td>Maxine</td>
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<td>University of Hawaii-Center for Island Climate Adaptation and Policy</td>
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<td>Cheung</td>
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<td>Chew</td>
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<td>Chow</td>
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<td>Pacific Disaster Center</td>
<td>Director, Humanitarian Assistance Programs</td>
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<td>Ramsay</td>
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Appendix C
March 8 and 9, 2011
Climate Change Workshop Agenda
## Appendix C Workshop Schedule

### Climate Change Transportation Vulnerability Workshop
March 8-9, 2011

**Day One (Morning) 0800-1130**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Speaker</th>
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</thead>
<tbody>
<tr>
<td>0800</td>
<td>1. Oli (15 Minutes)</td>
<td><strong>Kalani Souza</strong>, Executive Director, Olohana Foundation</td>
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<tr>
<td>0815</td>
<td>2. Welcome and Introductions (10 Minutes)</td>
<td><strong>Randolph Sykes</strong>, APA, Planning Program Coordinator, Oahu Metropolitan Planning Organization</td>
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<tr>
<td>0825</td>
<td>3. Why Are We Here? (10 Minutes)</td>
<td><strong>Brian Gibson</strong>, Executive Director, Oahu Metropolitan Planning Organization</td>
</tr>
<tr>
<td>0835</td>
<td>4. Painting the Climate Science Picture</td>
<td><strong>Dr. Chip Fletcher</strong>, Associate Dean and Professor, School of Ocean and Earth Science and Technology (SOEST)</td>
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<td></td>
<td>(45 Minute Presentation + 10 Minutes Discussion)</td>
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<tr>
<td></td>
<td>Visual presentation emphasizing the science of global climate change, observed climate changes in Hawaii, and stressors likely to affect Oahu's transportation infrastructure including:</td>
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<td></td>
<td>- Sea-level rise</td>
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<tr>
<td></td>
<td>- Inundation</td>
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<tr>
<td></td>
<td>- Wave overtopping</td>
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<tr>
<td></td>
<td>- Drainage</td>
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<td></td>
<td>- Slope stability</td>
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<td></td>
<td>Thinking of climate change as a affects multiplier.</td>
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<tr>
<td>0930</td>
<td>5. What if a Category Four Hurricane Came Onshore at Ewa? (30 Minutes)</td>
<td><strong>Dr. Kwok Fai Cheung</strong>, Professor, UH Department of Ocean and Resources Engineering</td>
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<tr>
<td></td>
<td>Visual presentation of the model showing a category four hurricane and related tidal surge on the south shore of Oahu; brief explanation of some of the impacts, e.g., flooding of airport and time to reopen, isolation of Sand Island, loss of harbor infrastructure, loss of 80% of housing, loss of power generation and oil refining capabilities and associated times to bring all back “on line.” Presentation should touch on model assumptions and how it might change in light of higher sea-levels and/or if category 4 hurricanes were more common for Hawaii.</td>
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**1000** &lt;Break&gt; **15 min** &lt;Break&gt; **15 min**
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1015  6. Urban Planning Challenges
       (20 Minute Presentation)
       Visual presentation of work currently being done to
       integrate climate science and urban planning;
       challenges faced in terms of datasets and levels of
       uncertainty

1035  7. New Perspectives on Engineering Challenges
       (20 Minute Presentation)
       Looking at the “Big Picture” and taking the
       broadest view of engineering; understanding how
       the environmentally variable drivers will affect
       design decisions now and in the future (reverse
       NEPA perspective)

1055  8. Existing Problems
       (15 Minute Presentation Each)
       Visual presentation on areas of Oahu that are
       currently experiencing affects of climate-related
       events on a regular basis, e.g., flooding in
       Mapunapuna and Campbell Industrial Park, affects
       of high waves on Kamehameha Highway on the
       north shore, rockfall at Makapuu, etc., as well as the
       impacts of historic events such as 2006 flooding,
       Hurricane Iniki, etc.

1130-1230 LUNCH!

Day One (Afternoon)  1230-1630

1230  9. Climate Change Challenges and Social Impacts in
       Oceania
       (20 Minute Presentation)
       Visual presentation of what is already happening to
       Pacific islands: Fiji, Kiribati, Samoa, Australia Council
       of State Governments report, etc.

1250  10. Reverse NEPA and making the process accessible
       to engineers and planners
       (30 Minute Presentation + 10 Minute)

1330  <Break> 15 min
       Move to assigned break-out room (see name tag)

1345  11. Asset and Impact Identification
       (60 Minutes)

1445  <Break> 15 min
       Move to assigned break-out room (see name tag)

Dr. Karl Kim, Professor, UH
Department of Urban and
Regional Development

Butch Wlaschin, PE, Director,
Office of Asset Management,
Office of Infrastructure, Federal
Highway Administration

Edwin H. Sniffen, PE, Highway
Administrator, Hawaii
Department of Transportation
And
Dolan Eversole, NOAA Coastal
Storms Program Coordinator for
the Pacific Region

Elizabeth E Fischer, RLA, ASLA,
APA, IAEM, USDOT Emergency
Coordinator, Federal Highway
Administration

Harrison B. Rue, Principal, ICF
International

Small, facilitated inter-
disciplinary groups
Engineers-Planners-Scientists
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<th>Time</th>
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<tr>
<td>1500</td>
<td>12. Asset and Impact Prioritization (60 minutes)</td>
<td>Small, facilitated interdisciplinary groups Engineers-Planners-Scientists</td>
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<td></td>
<td>Move to Keoni Auditorium</td>
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<tr>
<td>1605</td>
<td>13. Report Out and Consensus (25 minutes)</td>
<td>Brian Gibson, Executive Director, Oahu Metropolitan Planning Organization</td>
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<tr>
<td>1630</td>
<td>PAU!</td>
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### Day Two (Morning) 0800-1130

<table>
<thead>
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<th>Time</th>
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<tr>
<td>0800</td>
<td>Lucky We Live Hawaii: Culture and Place Based Lessons (15 minutes)</td>
<td>Ramsay Taum, Owner, LEI of the Pacific, LLC</td>
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</tr>
<tr>
<td>0815</td>
<td>1. Welcome and Day One Review (30 Minutes)</td>
<td>Brian Gibson, Executive Director, Oahu Metropolitan Planning Organization</td>
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<tr>
<td></td>
<td>(30 Minute Presentation + 10 Minutes Discussion)</td>
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<tr>
<td>0925</td>
<td>&lt;Break&gt; 15 min Move to assigned break-out room (see name tag)</td>
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<tr>
<td>0940</td>
<td>3. Asset Prioritization (75 Minutes) Fold together individual asset lasts developed on Day One into a single prioritized list</td>
<td>Small, facilitated interdisciplinary groups Engineers-Planners-Scientists</td>
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<td>Move to Keoni Auditorium</td>
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<tr>
<td>1100</td>
<td>4. Keynote: Climate Change Impacts to Humanitarian Risk and Regional Security (30 Minute Presentation)</td>
<td>Peter Colvin, Director of Humanitarian Assistance Programs, Pacific Disaster Center</td>
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</tr>
<tr>
<td>1130-1230</td>
<td>LUNCH!</td>
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### Day Two (Afternoon) 1230-1515

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<tr>
<td>1230</td>
<td>5. Commonalities and Differences in Prioritization (60 Minutes)</td>
<td>Large-group, facilitated discussion</td>
</tr>
<tr>
<td>1330</td>
<td>&lt;Break&gt; 15 min</td>
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1345  6.  Building Relationships
    (60 Minutes)
    How do we better integrate climate / environment / planning / engineering? Going forward → collaboration with common purpose.

1445  7.  Wrap-up and thank you
    (30 Minutes)

1515  PAU!

Large-group, facilitated discussion

Brian Gibson, Executive Director,
Oahu Metropolitan Planning Organization
Appendix D
Sea Level Rise and Storm Surge Modeling Maps
STORM SURGE MODELING FOR HONOLULU HARBOR AREA

Hurricane Scenario 1A: Maximum Flow Depth

Legend
Max. Water Depth (ft)
0 - 0.99
1.00 - 1.99
2.00 - 2.99
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
10.00 - 10.99
15.00 - 20.00

Sand Island
Sand Island Access Road Bridge
Piers 39/40 Young Brothers
Piers 1/2 Fort Armstrong

Scenario 1A
Review Copy
UH ORE
January 30, 2009
Hurricane Scenario 1A: Maximum Flow Depth
Kalaeloa Airport
1 Foot Sea Level Rise 2050
STORM SURGE MODELING FOR 3 WAIKIKI BRIDGES

Hurricane Scenario 1A: Maximum Flow Depth
Farrington Highway B1 - 3 Feet Sea Level Rise 2100
Farrington Highway D1 - 3 Feet Sea Level Rise 2100