Kakaako Makai - Hazard Assessment

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1/23/12

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Summary

By virtue of its location adjacent to the ocean, Kakaako Makai is vulnerable to marine hazards including sea level rise related to global warming, hurricane storm surge, and tsunami inundation.

Tsunami and hurricane storm surge models indicate that portions of Kakaako Makai would be inundated in worst case scenarios. There is no ability to predict the future timing of tropical cyclones or tsunamis other than to say they will continue to threaten Hawai´i and worst case scenarios should be planned for; they may occur at any time. Sea level rise will worsen the impact of both tsunamis and storm surge.

Modeling[1] indicates that because of global warming, the number of tropical cyclones in the central north Pacific may increase by the end of the century. Modeling[2] also indicates that the worst case tsunami, a tsunami originating from a mega-quake in the central Aleutian Islands, has not occurred in recent decades. This represents a "gap" in their occurrence. As mentioned above, portions of the Kakaako Makai region would be inundated in a worst case tsunami.

Sea level in Hawaii is rising now and may rise an additional 1 to 3 feet or more during the 21st century. Sea level rise will raise the water table in the Kakaako region and lead to drainage problems during high tide, especially after rainfall. Continued sea level rise will eventually create drainage problems throughout the entire tidal cycle. Road access will be affected by this flooding, a situation similar to what Mapunapuna has historically experienced. Sea level rise will increase the occurrence of wave splash, sea salt misting, and wave overtopping during high swell events.

Any development of Kakaako Makai can incorporate design features that adapt to and somewhat mitigate the impacts of these processes.

Is Global Warming Real?

Yes. The U.S. National Academies of Science, Engineering, and Medicine consider it a "settled fact" that global warming is real, it is largely caused by humans, and it is time to begin adapting to impacts.

"*Some scientific conclusions have been so thoroughly examined and tested, and supported by so many independent observations and results, that their likelihood of being found wrong is vanishingly small. Such conclusions are then regarded as **settled facts**. This is the case for the conclusions that **the Earth system is warming** and that much of this warming is very likely **due to human activities**…strong evidence on climate change underscores the need for actions to reduce emissions and begin **adapting to impacts**.*"

America's Climate Choices, U.S. National Academy of Science, National Research Council, 2011[3]

[1] Li, T., M. Kwon, M. Zhao, J.-S. Kug, J.-J. Luo, and W. Yu (2010) "Global warming shifts Pacific tropical cyclone location" Geophysical Research Letters, 37, L21804, doi:10.1029/2010GL045124.
[2] Butler, R. (2012) Re-examination of the potential for great earthquakes along the Aleutian Island Arc with implications for tsunamis in Hawaii. Seismological research Letters, v. 83.1, Jan/Feb 2012.
[3] National Academy Press, America's Climate Choices: 5 volume set. See the website http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=12781; last accessed 1/20/12.

In 2011 the National Academies published[4] the 5 volume set "America's Climate Choices", a report that concludes climate change is occurring; it is very likely caused by the emission of greenhouse gases from human activities; and it poses significant risks for a range of human and natural systems. These emissions continue to increase, which will result in further change and greater risks. Among these risks are negative impacts related to sea-level rise and associated marine hazards, which on low-lying coastal plains such as in Hawai'i, pose a range of threats to natural and human assets.

Sea Level Rise

In Hawaii, sea-level rise resulting from global warming is a particular concern. Riding on the rising water are high waves, hurricanes, and tsunami that will be able to penetrate further inland with every fraction of rising tide. In addition, the coastal groundwater table is likely to crop out above ground level and lead to widespread flooding and drainage problems. The physical effects of sea-level rise include:

1. Marine inundation of low-lying areas including developed portions of the coast,
2. Erosion of beaches and bluffs,
3. Salt intrusion into aquatic ecosystems,
4. Higher water tables leading to reduced drainage, flooding, and other effects, and
5. Increased flooding and storm damage due to heavy rainfall that cannot adequately drain.

The present state of research indicates that global mean sea level may rise 1 to 3 feet or more during the 21st century. Satellite monitoring of the ice sheets on Greenland and Antarctica indicate that the melt rate, added to the thermal expansion of shallow sea water across the world's oceans, may raise global mean sea level by approximately 1 ft[5] by mid-century. Models indicate that global mean sea level may rise by 3 ft or more by the end of the century.[6]

Although the range 1-3 ft is the most probable range of sea level rise this century indicated by present modeling, **significant unknowns remain and sea level in some models has been projected to rise as much as 6 ft by end of the century**. The exact level of the ocean in the future is a matter of great uncertainty and all planning should remain flexible and in touch with the latest scientific findings regarding future sea level rise. The following estimates are based on a review of the current peer-reviewed literature projections of future sea level rise.

1 ft – (mid-century) At 1 ft of sea level rise, drainage from surface streets during heavy rainfall will be impeded at high tide. Figure 1 provides a picture of what this will look like. Splash from high waves will increase.

[4] National Academy Press, America's Climate Choices: 5 volume set. See the website http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=12781; last accessed 9/15/11.

[5] Rignot, E., Velicogna, I., van den Broeke, M.R., Monaghan, A., and Lenaerts, J., 2011 "Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise," Geophysical Research Letters, v. 38, LO5503, doi:10.1029/2011GL046583.

[6] Vermeer, M. and Rahmstorf, S., 2009 "Global sea level linked to global temperature," Proceedings of the National Academy of Sciences, http://www.pnas.org/content/early/2009/12/04/0907765106.full.pdf.

2 ft – (late mid-century) At 2 ft of sea level rise Ala Moana Blvd. and some nearby streets will experience water table inundation during high tide. Surface runoff during rainfall will be impeded.

3 ft – (late century) At 3 ft of sea level rise travel along Ala Moana Blvd. and most nearby cross streets will be impossible at high tide. Portions of the Kakaako Makai region will be flooded inundated by the water table at high tide.

4 ft – (end of century, early next century) At 4 ft of sea level rise the region will be impassable during much of the tidal cycle.

Models of risk and vulnerability to sea level rise provide guidance in identifying lands that may by vulnerable to sea level rise impacts (Figure 2a-d). It is important to stay in touch with the latest scientific findings about sea level rise. New information is continuously becoming available and assessments change frequently. Planning should remain flexible and take the approach that knowledge of future sea level rise is continually improving. Thus a "no-regrets" approach toward development is appropriate.

Figure 1. Drainage problems during heavy rainfall will worsen as a result of sea level rise.[7]

[7] Fletcher, C.H., Boyd, R., Neal W.J., Tice, V. (2010) *Living on the Shores of Hawaiʻi: Natural Hazards, the Environment, and Our Communities*, University of Hawaiʻi Press, 371p.

Figure 2a. Flooding at high tide following 1 ft of sea level rise; mid century. Note: map does not indicate hazard due to wave overtopping, tsunami, storm surge, or intense rainfall. Colored areas indicate regions subject to drainage problems related to rainfall, groundwater rising to land level, and ocean water flooding into storm drainage network.

Figure 2b. Flooding at high tide following 2 ft of sea level rise; late mid-century. Note: map does not indicate hazard due to wave overtopping, tsunami, storm surge, or intense rainfall. Colored areas indicate regions subject to drainage problems related to rainfall, groundwater rising to land level, and ocean water flooding into storm drainage network.

Figure 2c. Flooding at high tide following 3 ft of sea level rise; late century. Note: map does not indicate hazard due to wave overtopping, tsunami, storm surge, or intense rainfall. Colored areas indicate regions subject to drainage problems related to rainfall, groundwater rising to land level, and ocean water flooding into storm drainage network.

Figure 2d. Flooding at high tide following 4 ft of sea level rise; end of century, early next century. Note: map does not indicate hazard due to wave overtopping, tsunami, storm surge, or intense rainfall. Colored areas indicate regions subject to drainage problems related to rainfall, groundwater rising to land level, and ocean water flooding into storm drainage network.

It is useful to compare the Kakaako Makai region to the broader region of Honolulu and Waikiki in terms of relative risk and vulnerability under higher sea level. Figure 3 maps the vulnerability to 3.3 ft (1 m) of sea level rise on the south shore from Sand Island to the Diamond Head end of Waikiki.

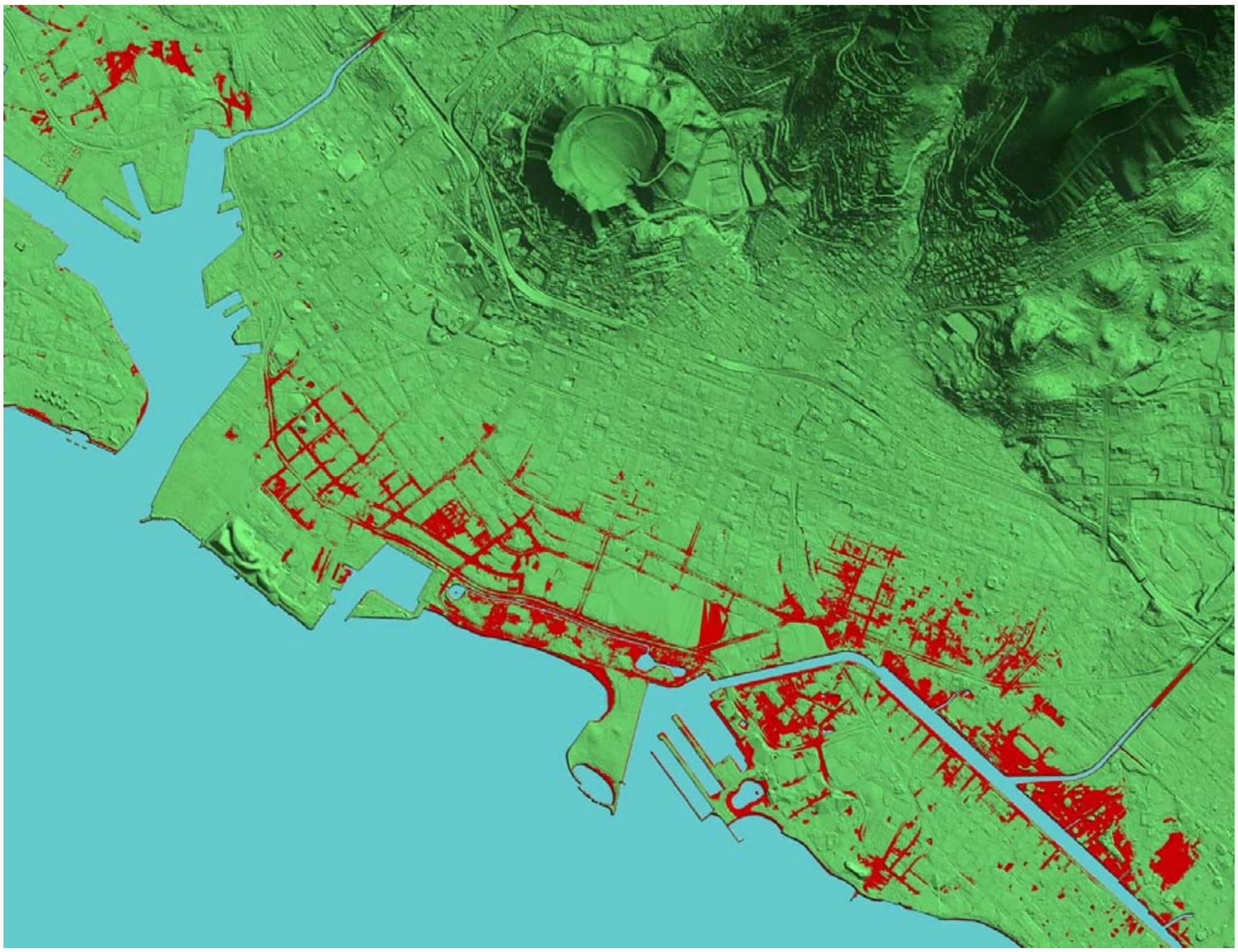


Figure 3. South Shore flooding at high tide following 3.3 ft (1 m) of sea level rise; approximately end of century, early next century. Note: map does not indicate hazard due to wave overtopping, tsunami, storm surge, or intense rainfall. Colored areas indicate regions subject to drainage problems related to rainfall, groundwater rising to land level, and ocean water flooding into storm drainage network.

Tsunami

The tsunami hazard has been modeled using the 5 worst historical tsunamis to have hit the Hawaiian Islands, and the 5 worst model scenarios generated by computer runs simulating mega-thrust quakes at points around the Pacific including the south shore of the Big Island. The official tsunami hazard maps (Figure 4) for the state of Hawaii are based on the worst case of the 10 model runs. The map in Figure 3 reveals that the Kakaako Makai region is vulnerable to a worst case tsunami.

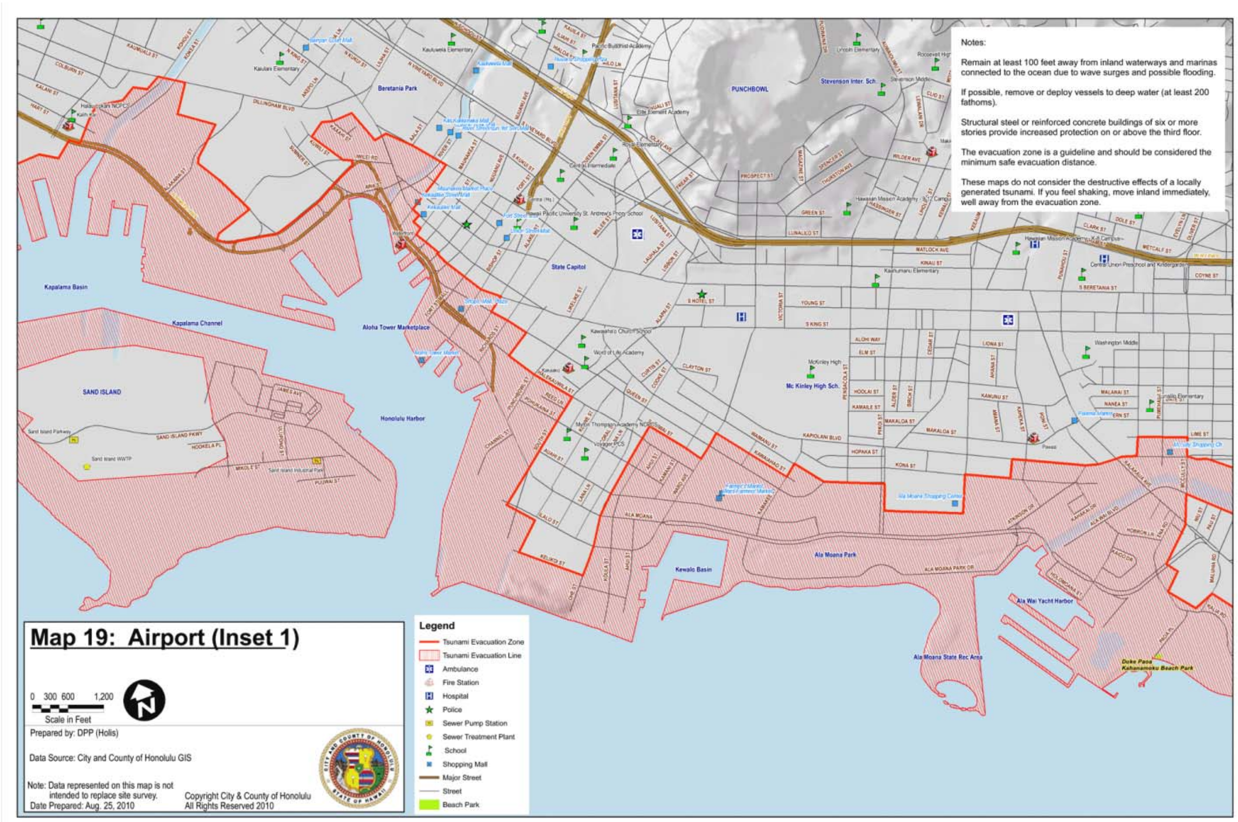


Figure 4. Tsunami inundation map: http://tsunami.pdc.org/hazards/tsunami/#oahu

Modeling[8] indicates that the worst case tsunami, a tsunami originating from a mega-quake in the central Aleutian Islands, has not occurred in recent decades. This represents a "gap" in their occurrence. As mentioned above, portions of the Kakaako Makai region would be inundated in a worst case tsunami.

[8] Butler, R. (2012) Re-examination of the potential for great earthquakes along the Aleutian Island Arc with implications for tsunamis in Hawaii. Seismological research Letters, v. 83.1, Jan/Feb 2012.

Hurricane Storm Surge

Dr. Fai Cheung has modeled the occurrence of a category 4 hurricane coming onshore at Ewa (see appendices). This location of the eye making landfall constitutes a worst case scenario for storm surge for the Honolulu/Kakaako business district. As shown in Figure 5 the Kakaako Makai region is moderately vulnerable to storm surge in this scenario and may experience up to 3-10 ft of flooding.

Modeling[9] indicates that because of global warming, the number of tropical cyclones in the central north Pacific may increase by the end of the century.

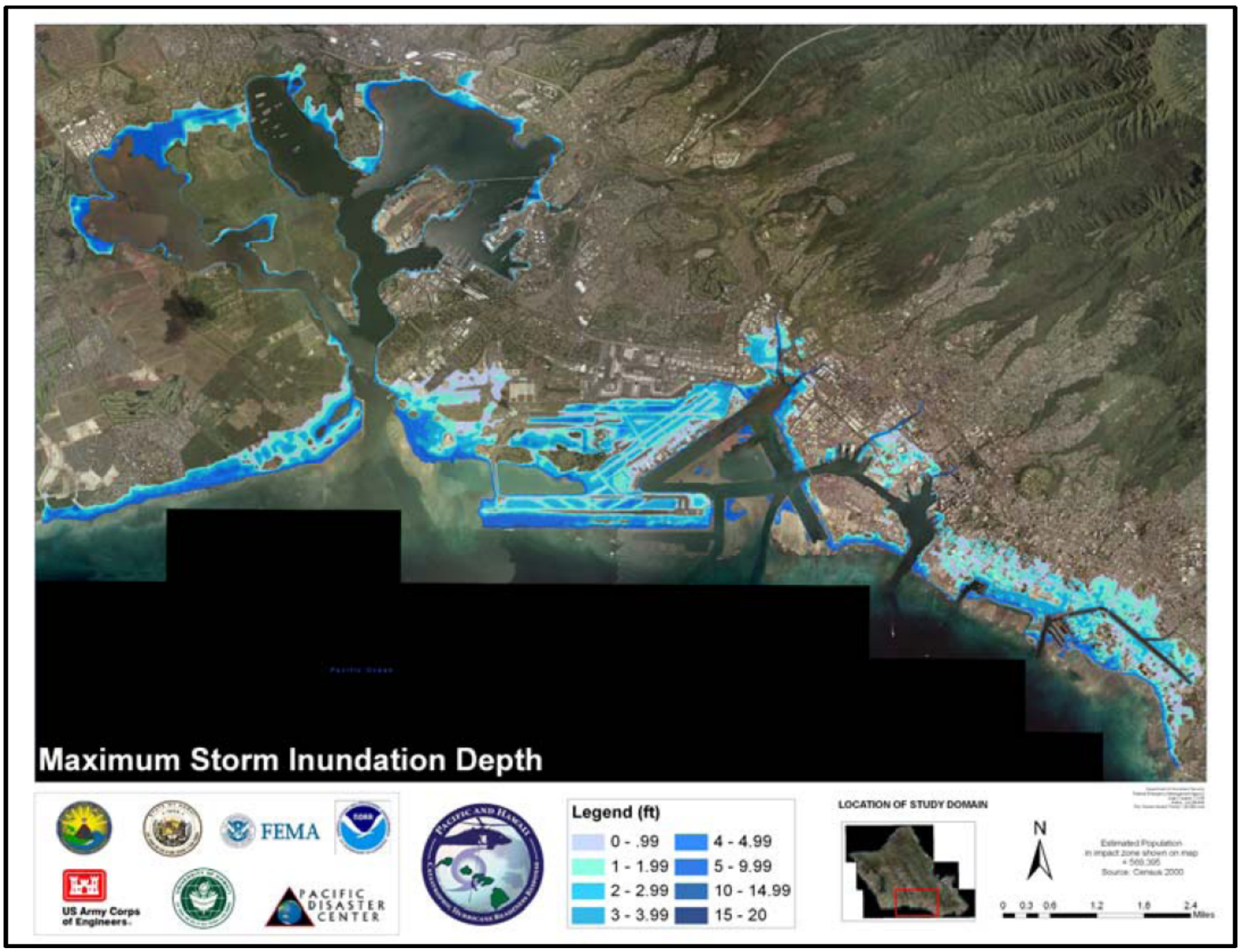


Figure 5 Modeled maximum flow depth with inundation by storm surge: Hurricane Iniki re-routed to Oahu at high tide; eye landfall in Ewa; the worst case for Honolulu. Figure from Dr. Fai Cheung, University of Hawaii, Ocean and Resources Engineering Department (Appendix 1).

9 Li, T., M. Kwon, M. Zhao, J.-S. Kug, J.-J. Luo, and W. Yu (2010) "Global warming shifts Pacific tropical cyclone location" Geophysical Research Letters, 37, L21804, doi:10.1029/2010GL045124.

Analysis

No investigation exists describing the combination of sea level rise and other marine inundation processes. However, an investigation of this is planned for production in late 2012 by the NOAA Coastal Storms Program, University of Hawaii Sea Grant College.

Kakaako Makai is vulnerable to partial inundation by passive sea level rise, and high velocity flow during hurricane storm surge and tsunami inundation. Although none of these processes has been modeled to fully submerge the entire peninsula, as sea level continues to rise full submergence becomes a growing possibility.

The seaward portion of the Kakaako Makai sits at higher elevation than the cross streets and main streets that lay mauka of the peninsula. All modeled hazard results indicate the location of greatest vulnerability lies among these surface streets. Hence, access to the peninsula is more vulnerable than the peninsula itself. However, wave overtopping has not been modeled and this effect will impact the shoreline area more than surface streets.

Modeled hazards are event based and their impact will be temporary. Even sea level rise presents the greatest hazard at high tide with reductions at lower tide states. Hence, development can be designed to withstand these events and thereby extend useful lifetimes potentially for several decades.

Design features may include an elevated base to any structures, timed-gated storm drains to prevent high tide flooding, groundwater table pumping at high tide, raised surface streets and adjacent lots, minimized external building features that threatened the building envelop in high winds, ability to withstand high water flow, and independent energy, waste and water capability.

The No Regrets Planning Approach

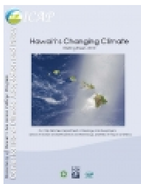
Adaptation and hazard mitigation planning for coastal hazards such as sea-level rise and climate change serves to protect new infrastructure and investment, natural resources and public health and safety, both now and in the future. Much of the growing literature in the hazard mitigation and climate adaptation field suggests employing a "no regrets" approach to planning for hazards and developing avoidance and accommodation strategies that are based on risk and vulnerability assessments early in the development planning cycle. Because sea-level rise and climate change exacerbate existing coastal hazards, adapting now ultimately will lessen future economic, social, and environmental impacts of rising sea levels.

Current scientific research strongly supports climate change as a driver of sea-level rise in the Hawaiian Islands and around the world. While the physical and environmental impacts of rising sea levels are not certain, there is sufficient evidence to act on the "precautionary principle" of land use planning in developing adaptation and mitigation strategies based on the results of preliminary risk and vulnerability assessments. The necessity for "proactive adaptive management" in the face of this uncertainty is an important policy consideration, as is the important role to be played by state and local governments in implementing adaptation measures and development of new climate change and hazard policy.

The *SLR Policy Toolkit* encourages action and makes the Tool Kit ready for use by state and local governments. An action matrix is organized according to the three major approaches to sea-level rise: accommodation, protection, and retreat. In addition to summarizing the policy tools and initial steps for accommodation, protection, and retreat, each action matrix identifies the lead agency and proposes a time frame for specific state and local government actions. The tools are ranked based on impact and feasibility, with the highest-ranking policy tools discussed first. Additional sources of local hazard mitigation guidance that may be useful in developing a site-specific adaptation strategy can be found at: http://seagrant.soest.hawaii.edu/publications

Useful Resources:

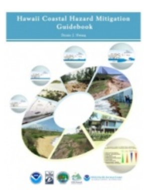
- ***Hawai'i's Changing Climate, Briefing Sheet, 2010***



http://seagrant.soest.hawaii.edu/hawaiis-changing-climate-briefing-sheet-2010

The purpose of this briefing sheet is to describe how global climate change is influencing the Hawai□i climate, as published in peer-reviewed scientific journals and in government reports and websites.

- ***The Hawaii Hazard Mitigation Guidebook***

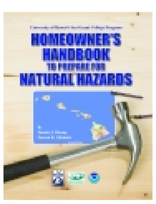


http://seagrant.soest.hawaii.edu/hawaii-coastal-hazard-mitigation-guidebook

Designed for a wide and varied audience from planners and architects to homeowners and government agencies, the guidebook complements the Federal Emergency Management Agency's Coastal Construction Manual with a special emphasis on land use planning and siting. The purpose of the guidebook is as a resource to reduce the risk to coastal development by planning for natural hazards such as erosion, flooding, tsunamis and hurricanes.

- ***The Hawaii Homeowner's Handbook to Prepare for Natural Hazards***

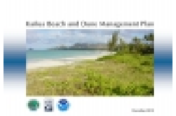
http://seagrant.soest.hawaii.edu/sites/seagrant.soest.hawaii.edu/files/publications/homeowners_handbook_to_prepare_for_natural_hazards.pdf



This handbook was created to help homeowners prepare for a natural hazard so that risks to family and property may be reduced. While it is never possible to eliminate all damage from a natural hazard, a homeowner can take action and implement many small and cost-effective steps that could significantly lower your risk.

- ***Kailua Beach and Dune Management Plan***

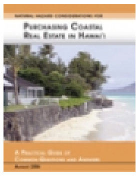
http://seagrant.soest.hawaii.edu/sites/seagrant.soest.hawaii.edu/files/publications/kailua_beach_mgmt_plan.pdf



Describes proactive policies and practices that promote appropriate management of coastal resources, UH Sea Grant partnered with the Department of Land and Natural Resources to develop beach management plans for selected shorelines throughout the state.

- ***Natural Hazard Considerations for Purchasing Coastal Real Estate in Hawaii: A Practical Guide of Common Questions and Answers***

http://seagrant.soest.hawaii.edu/sites/seagrant.soest.hawaii.edu/files/publications/Purchasing_Coastal_Real_Estate.pdf



This guide focuses on basic questions to consider as an investor in coastal real estate. Whether you are looking to buy a developed or an undeveloped lot, there are critical issues that should be examined and assessed before committing to a purchase.

- ***SmartGrowth For Coastal and WaterFront Communities***

http://seagrant.soest.hawaii.edu/sites/seagrant.soest.hawaii.edu/files/sbcd/additionalpubs/smartgrowth_fullreport.pdf

How can smart growth strategies help coastal and waterfront communities manage growth and development while balancing environmental, economic, and quality of life issues? How can communities on the water adapt smart growth strategies to fit their unique character? This publication will help communities answer these questions. It is specifically targeted to anyone who plans, designs, builds, approves, or has an interest in development at the water's edge.

Conclusion

The Kakaako Makai area is vulnerable to coastal hazards. The vulnerability will increase with continued sea level rise. Development can utilize designed features to minimize future risk such as:

1. Avoid slab on grade construction, utilize a building design that allows flood water to flow on the ground beneath a building with no impact to the building;
2. Maintain the elevation of streets as they are repaved, raise the street level on pace with sea level rise;
3. Raise buildings and land adjoining streets with revised building codes so that they are not flooded by runoff from higher streets,
4. Engineer the drainage network with one-way flow boots and/or timed gates that close at high tide,
5. At high sea levels consider the cost and benefit of pumping down the water table,
6. Minimize building features that are vulnerable to high winds and waves, design protection of the building envelop in high winds and waves,
7. Design buildings to be energy independent in order to survive grid failures,
8. Design access to the building to be elevated and off grade,
9. Underground all utilities
10. Consider appropriate uses for multiple properties based on their hazard exposure.

APPENDIX 1

MODELING OF STORM SURGE AND WAVES IN PEARL HARBOR AT PROJECTED SEA LEVELS

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December 21, 2011

Project Description

Recent global and local projections suggest the sea level will be on the order of 1 m or higher than the current level by the end of the century. An elevated sea level due to global warming exacerbates flood hazards by allowing storm surge and waves further into the coastal zone and reducing the capacity of drainage systems in discharging the floodwater. The proposed project will identify risks and vulnerabilities of the facilities at Pearl Harbor to flood hazards associated with hurricane landfalls at future sea levels.

The proposed project will use an updated version of Cheung et al. (2003, 2007) that provides a more complete account of the interactions among the various hydrodynamic processes during a hurricane landfall. The model package has four components to simulate: (1) meteorological conditions, (2) astronomical tides and storm surge, (3) wave generation, propagation, and nearshore transformation, and (4) surf-zone processes and inundation onto dry land. These processes of varying temporal and spatial scales are described by parametric hurricane models validated by Phadke et al. (2003), the third-generation spectral wave models WW3 of Tolman (2008), the coastal wave model of Booij et al. (1999) adapted by Filipot and Cheung (2011) for fringing reef environments, a storm surge and tide model adapted from the tsunami model of Yamazaki et al. (2009, 2011), and the shock-capturing Boussinesq-type model of Roeber et al. (2010) and Roeber and Cheung (2011). An important part of the proposed project is a digital elevation model (DEM) of the Hawaiian Islands that includes LiDAR datasets from 40 m water depth to 15 m elevation at 1 to 3 m resolution and multi-beam survey data at 50 m resolution along the island chain. Fig. 1 shows an example of the digital elevation model along the south shore of Oahu. The digital elevation model resolves detailed reefs and land features for inundation mapping.

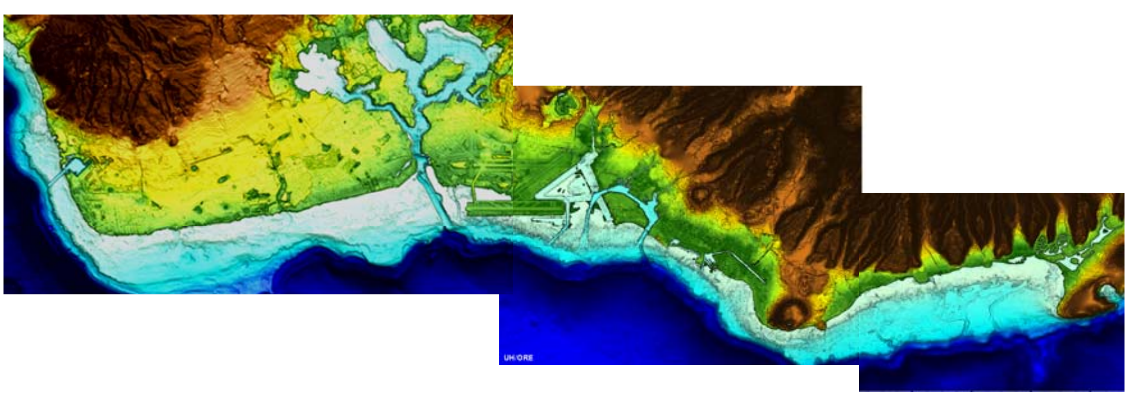

Fig. 1 Example from Hawaii Digital Elevation Model.

The PI used an earlier version of the model package to develop the inundation map for the Hawaii Catastrophic Hurricane Operation Plan of FEMA (OPLAN 2009). Fig. 2 provides an example of the data products, which are being used in the annual Makani Pahili *hurricane exercise* in Hawaii. Current applications of the model package include hurricane inundation mapping of the Honolulu coast at for NOAA Coastal Storm Program and morphological impact analysis at Eglin AFB and Camp Lejeune in collaboration with Woods Hole Oceanographic Institute for SERDP. In the proposed project, we will model the hurricane landfall scenarios defined by the NWS Central Pacific Hurricane Center for the FEMA OPLAN at future sea levels. This will provide the flow depth and velocity maps as well as the inundation limits at Pearl Harbor to identify risks and vulnerabilities of the facilities.

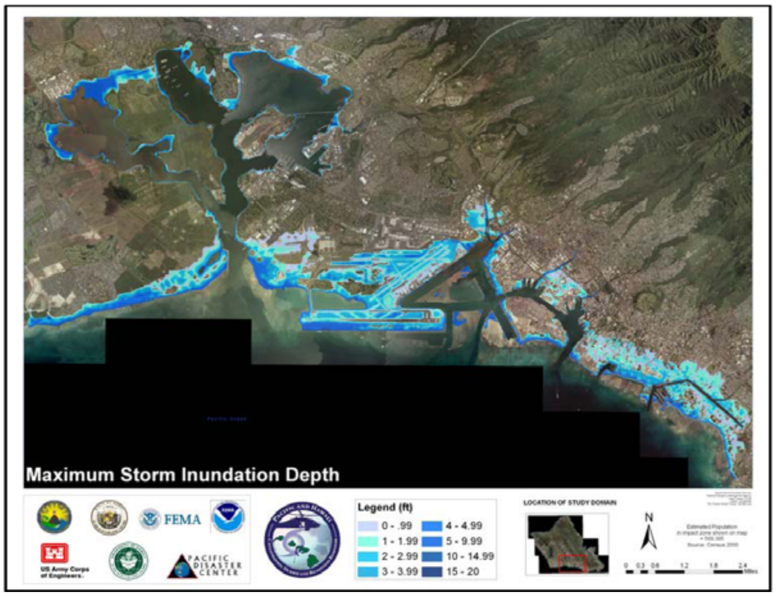

Fig. 2 Hurricane Inundation Map from Hawaii Catastrophic Hurricane Operations Plan Version 2.0.

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