Annex B: Intelligence – Hawaii Catastrophic Hurricane OPLAN
July 16, 2009 Version 2.0

1.0 BACKGROUND

This annex describes the environmental effects of a category 4 hurricane making landfall on the heavily populated southern shore of Oahu. The modeling used for this catastrophic scenario was developed using the best available science, and was a joint effort consisting of Federal, State and non-profit organizations. The modeling team was led by the National Weather Service – Honolulu (NWS), which created 12 hurricane scenarios based on local and regional weather patterns and historical hurricane data. The University of Hawaii's (UH) Department of Ocean and Resources Engineering (ORE) developed the storm wave and inundation model package, the Federal Emergency Management Agency (FEMA) conducted rain modeling with Hazards U.S. Multi-Hazard (HAZUS) and provided baseline Light Detection and Ranging (LIDAR) imagery, and the Pacific Disaster Center (PDC) focused on wind exposure. In addition, the U.S. Army Corps of Engineers (USACE) contributed statistical and regression models to UH. Based on the compiled results of the modeling efforts presented here, State and Federal response agencies can make informed decisions about emergency efforts during a catastrophic hurricane. The ability to make decisions is enhanced by the comprehensive Decision Support Tool (DST) that was delivered with this plan. The DST is available in Google Earth and ArcReader platforms. The DST is maintained by Hawaii State Civil Defense (SCD) and FEMA Region IX.

2.0 SITUATION

A category 4 hurricane has sustained winds of 131-155 mph (114-135 kts), causing extreme structural damage and beach erosion. The central Pacific hurricane season runs from 1 June to 30 November, with peak activity in late summer when ocean temperatures are warmest. Hawaii is unique given its topography and position in the Pacific Ocean. Hawaii's topography channels and amplifies winds across ridges and through island valleys. The terrain also lends itself to destructive flash floods and landslides when excess rains on mountain slopes occur. Given these variables, even a relatively weak hurricane making landfall in the Hawaiian Islands will result in substantial damage and economic loss.

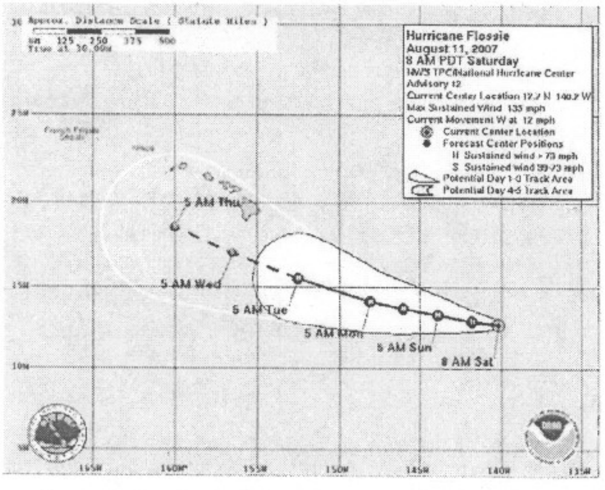

Figure 2.0-1: Cone of Uncertainty for Hurricane Flossie

A conical path predictor, or 'cone of uncertainty,' (see Figure 2.0-1) is used to aid in hurricane forecasting, and tracks three to five days outward from the current position of a storm. Historically, storms have a 60-70% chance of staying within the area of a three-day cone. The NWS issues a hurricane watch when there is a possibility of landfall within 48 hours. A hurricane warning is issued when landfall is likely within 36 hours.

a. Defining the Scenario – The National Weather Service (NWS).

The NWS conducted a study analyzing the paths of pacific cyclonic systems from 1949-1995. Based on that data, there is an 80% chance during any given hurricane season that a hurricane-strength system will pass within 360 nautical miles of the Hawaiian Islands. Storms that approach from due east have historically weakened before reaching Hawaii due to strong upper level wind shear and cooler sea-surface temperatures in the northern Pacific. A category 5 hurricane making landfall somewhere in the island chain is highly unlikely due to these atmospheric conditions and ocean temperatures. Storm surge from a category 4 hurricane would normally be 13-18 feet along areas with a wide, shallow continental shelf. The steep slopes surrounding the islands limit the height of the storm surge but can potentially produce much larger storm waves as the hurricane comes ashore. However, the presence of fringing reefs along the coastline has the potential to significantly dissipate the hurricane's wave energy. The wave energy from a category 4 hurricane would, however, affect the entire state.

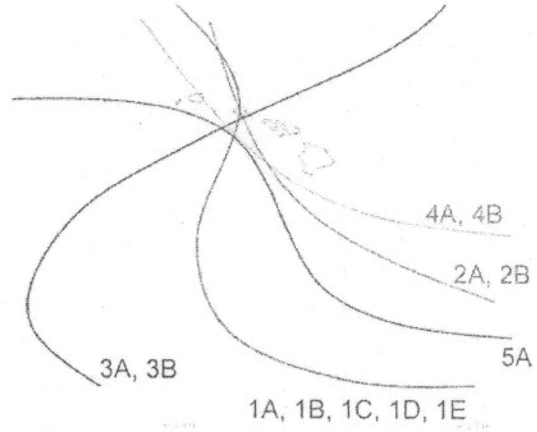

Figure 2.0-2: Scenario Tracks

Twelve scenarios were created by the NWS, based on historical tracks. Each scenario takes into account local atmospheric conditions, location of landfall, speed of forward movement, central pressure, maximum sustained winds, and size of the storm.

The NWS modeling team determined that scenarios 1A, 1B, 2A and 3A are most likely to create the greatest catastrophic results for the Island of Oahu, and were therefore selected for the focus of the initial near-shore modeling efforts. Each scenario however, impacts the domain area differently, depending on the hurricane size, speed, and direction of the winds. Therefore, a combined catastrophic event encompassing effects of all 12 scenarios is presented for the entire domain area where a category 4 hurricane could make landfall.

b. Storm Inundation Mapping – The University of Hawaii (UH).

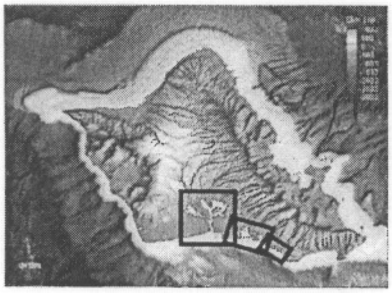

Figure 2.0-3: The three Study domain areas: Pearl Harbor, Honolulu and Waikiki.

The modeling package contains 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 run-up onto dry land. The different time and length scales of these processes allow the physical phenomena to be modeled separately and the interactions included through data transfer between the models. Each simulation covers three nested computational domains of increasing resolution for (1)

Hawaii, including ocean surface to the south, east, and west; (2) Oahu, and the steep island shelf; and (3) a nearshore region on the south shore of Oahu (Waikiki, Honolulu Harbor, and Pearl Harbor), as seen in Figure 2.0 -3.

As mentioned previously, of the 12 hurricane scenarios selected for this project, UH calculated the individual impact from each scenarios, as well as the combined comprehensive, or worst case impact. In addition to the 12 original scenarios, 3 additional scenarios based on a 1B type hurricane making landfall at several locations on the south shore of Oahu were included to ensure that the worst case impact was captured in the analysis. The final maximum water depth and maximum velocity results are presented in figures 2.0-4 and 2.0-5. The hurricane scenarios are all calculated under high tide conditions.

The total maximum water depth considers the water generated by the waves and the variable storm water level over the entire hurricane event. Water depth is defined as the total elevation of the water surface over the topography, which includes the effects of the hurricane storm surge, surf, and swash zone waves. For example, scenario 1A produced the most storm inundation near downtown Honolulu and Pearl Harbor, while scenario 1B had the greatest inundation in Waikiki. Total water depth in these domains can reach up to 20 feet at the shorelines and in low-lying areas. Figures 2.0-4 and 2.0-5 give the maximum water depth and maximum velocity expected by the combined impact of all hurricane scenarios.

The modelings of the scenarios show a large increase of the storm surge water level in Pearl Harbor and Keehi Lagoon as hurricane winds push the water ashore. Since the water level increases over a period of several hours during a time of high winds, the water cannot easily drain back to the ocean. Therefore it is expected that the surge within the port of Honolulu will experience ponding and continued flooding that will last for several hours.

In the scenarios tested, Sand Island is not completely inundated by the storm surge and associated wave action. This is because the winds become less effective in pushing the deep channel water onshore, and the shallow reef in front of Sand Island causes waves to break before reaching shore. Based on discussions with the UH modeling team, there is up to 1ft. of uncertainty in the surge level around Sand Island. However, the eastern half of Sand Island is less than 1ft. above the calculated surge. This is too close to the model uncertainty to assume this area will not be flooded during a catastrophic hurricane event. Emergency managers must consider the possibility of overtopping of the Sand Island seawalls and the potential inundation over the near-level ground surface. The potential flood hazard areas given in Figure 2.0-6 show the likely inundation areas assuming the storm surge overtops the seawalls. In addition, debris generated (including structural components of buildings, aggregate, and shipping containers) from the flooding and wind will severely damage infrastructure in the port. Expectations are that Sand Island shipping, sewer, and power infrastructure will be completely inoperable following a catastrophic hurricane event.

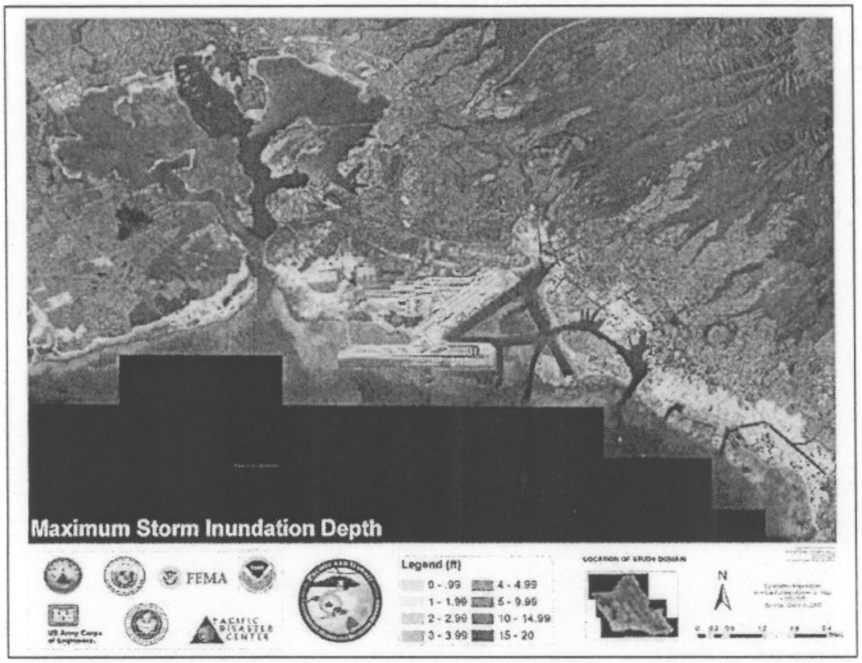

Figure 2.0-4: The maximum water depth expected during a catastrophic hurricane event, compiled from all hurricane scenarios tested.

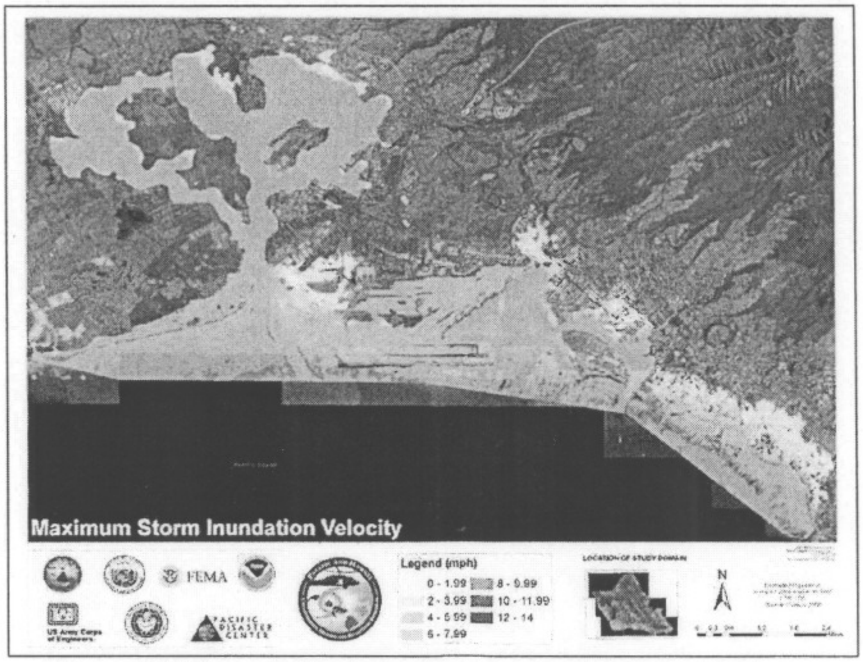

Figure 2.0-5: The maximum velocity of water coming ashore (up to 14 miles per hour). The speed of storm surge, surf, and swash zone waves combined with the water depths are expected to cause severe damage to these domains.

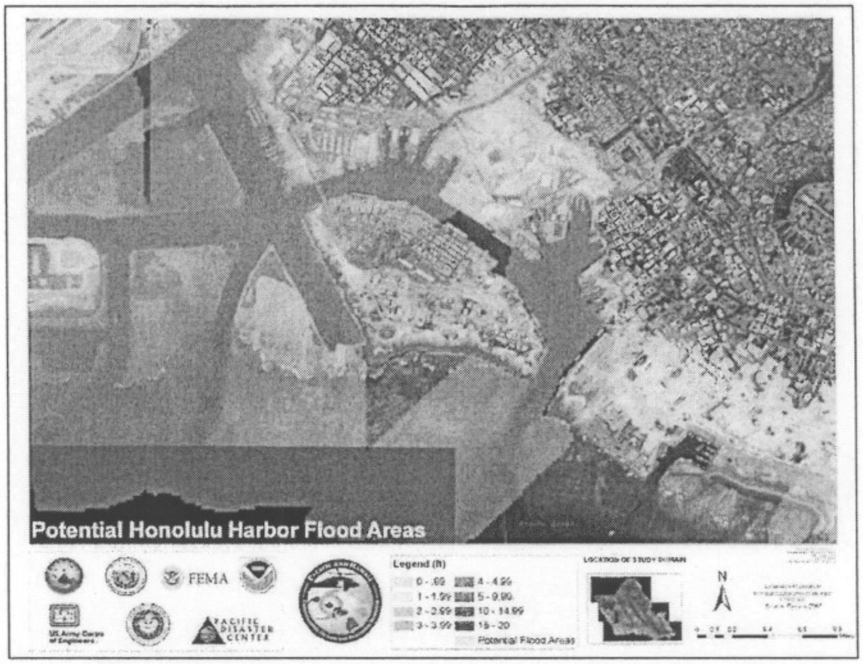

Figure 2.-6: Flood awareness areas, and areas of inundation on Sand Island due to seawall overtopping.

c. Wind Mapping – Pacific Disaster Center (PDC).

Orographic speed-up effects can be significant in areas with complex terrain, such as Hawaii. A study was conducted in 2002 by Chock, Peterka, and Cochran that developed a methodology to estimate directional speed-up factors on the islands of Oahu, Kauai, Lanai, and Molokai. Physical replicas of the Hawaiian Islands based on 10 meter elevation data were used in a boundary layer wind tunnel to collect wind speed data for 358 sample points on Oahu and Kauai from 16 approach angles. The 5,728 resulting records were then used to develop a predictive model to estimate speed-up factors for areas of the islands not sampled. The model incorporated several landform and topographic terrain variables. The directional speed-up effects themselves indicate how wind passing a certain point and coming from a certain direction speeds up or slows down relative to the speed at a flat, unobstructed coastal site. The speed-up factors are represented as percentages. Contours of the mean and peak speed-up factors were provided to PDC as part of a previous contract and served as the basis for modeling potential wind exposure.

When calculating final estimated wind speeds in a Geographic Information System (GIS), PDC used a layer representing the maximum peak speed-up expected from any direction for each grid cell. Peak speed-ups are based on three-second peak gusts and are adjusted to a 10 meter height. By incorporating the maximum of all 16 peak directional speed-up factors, the importance of accurately and precisely anticipating a hurricane's track, wind speeds and direction over space and time is lessened. This is a conservative method that can account for uncertainty and provides a "worst case scenario" for a given input wind speed.

PDC produced seven final exposure maps based on the maximum wind speeds provided for scenarios 1A, 1C, 1D, 1E, 4B, and 5A. These scenarios reflect a strong category 4, a weak category 4, a weak category 3, a strong category 1, a weak category 1, and tropical storm force winds. PDC also calculated estimated final wind speeds for a category 2 hurricane. Because the maps represent the result of maximum speed-up from any direction, their use is not limited to specific directional scenarios. The maps can be seen as an estimation of maximum wind speeds for storms approaching from any direction. A map based on sustained winds of 149 mph is included as Figure 2.0-7.

While many of the highest maximum speed-ups are located in lightly populated regions, urban and agricultural areas in the middle of Oahu could experience speed-up effects of 160 percent. The same is true of the populated slopes and valleys surrounding the Honolulu area. The populated northern face of southeast Oahu is also susceptible to strong speed-up effects. In a strong category 4 storm (Scenario 1A), this would mean potential gusts of over 200 mph in some urban residential areas. Even a category 1 storm (Scenario 4B) might produce gusts of up to 120 mph in these places.

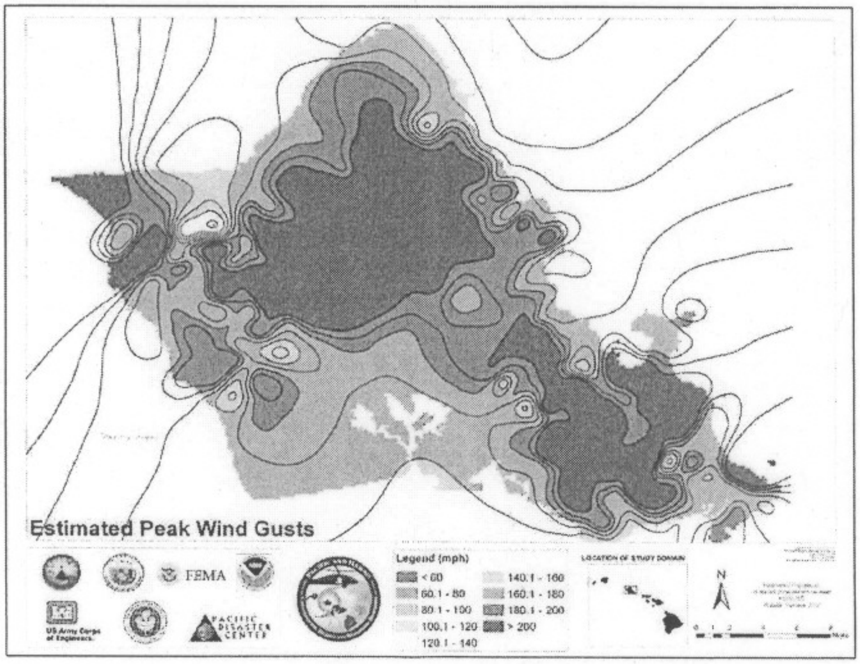

Figure 2.0-7: Peak estimated wind speeds (gusts) for a strong category 4 hurricane, like Scenario 1A, coming from any direction.

d. Rain Mapping – The Federal Emergency Management Agency (FEMA).

Flooding effects from rain have been calculated by running HAZUS for flooding and hurricane winds. In addition, flooding from riverine sources were analyzed using the latest Digital Flood Insurance Rate Map (DFIRM) database.

The primary purpose of HAZUS is to provide a methodology and software application to develop multi-hazard losses on a regional scale. The region specified in this model is the Island of Oahu, with scenarios run for the areas of Pearl Harbor, Honolulu, and Waikiki. An interpretation of the rainfall effects is presented as riverine flooding across Oahu.

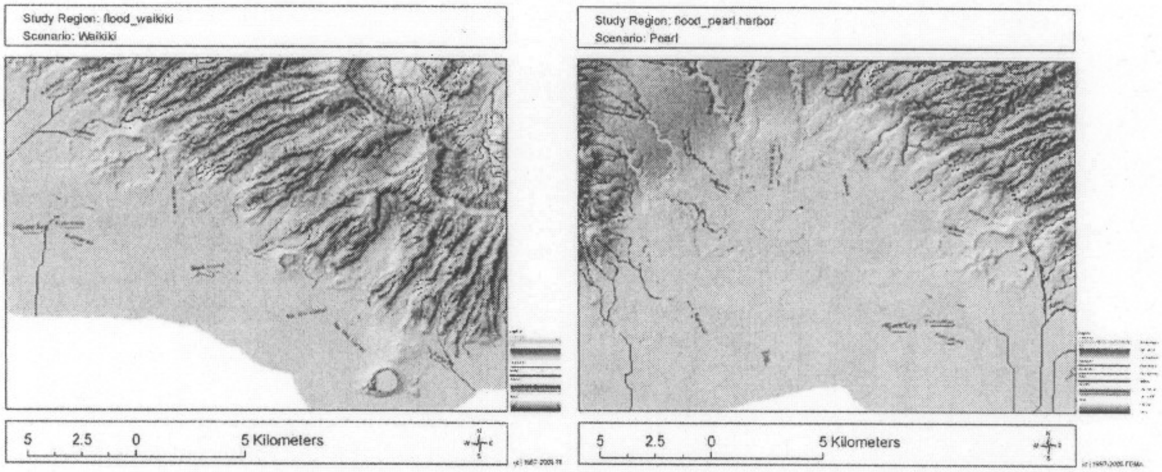

Figure 2.0-8: HAZUS flooding awareness areas in Honolulu, Waikiki, and Pearl Harbor

Flooding, when combined with UH analysis of storm surge inundation, is anticipated to have a significant impact on critical infrastructure. See Section 3 for more details on combined effects.

HAZUS estimates the amount of debris generated by flooding for the Pearl Harbor, Honolulu, and Waikiki areas to be 217,636 tons. To remove the debris would require 8,706 truckloads (25 tons/truck). The tonnage translates to 906,816 cubic yards of debris using conversion factors for construction and demolition debris.

In the Honolulu and Waikiki areas, approximately 40% of the buildings are expected to be at least moderately damaged by flood waters, and almost 2% to be substantially damaged. At Pearl Harbor, 34% of the buildings are expected to be moderately damaged and 3% to be substantially damaged. Moderately and substantially damaged are defined by the HAZUS technical manual as 11-50% damaged, and greater than 51% damaged, respectively. The majority of moderately damaged and all substantially damaged buildings are residential structures.

Building Exposure by Occupancy Type for Oahu

Table 2.0-1: The most significant structural damage is expected to be residential, which constitutes over 80% of the buildings on Oahu.

Occupancy	Exposure ($ Amount)	Percent of Total
Residential	65,267,574,000	81.90%
Commercial	10,628,443,000	13.30%
Industrial	1,318,260,000	1.70%
Agricultural	281,972,000	0.40%
Religious	885,560,000	1.10%
Government	578,137,000	0.70%
Education	756,293,000	0.90%
Total	79,716,239,000	100.00%

Total building loss from flooding for the modeled areas is an estimated $2.9 billion. There is also an economic loss associated with business interruption from flooding estimated at $26.25 million. These figures are anticipated to be much higher following a category 4 hurricane, considering the additional structural damage and economic interruptions associated with the effects of hurricane force winds and storm inundation.

Building Exposure by Occupancy Type for Pearl Harbor/Honolulu/Waikiki

Table 2.0-2: Residential structures also make up over 75% of the three nearshore modeled areas.

Occupancy	Exposure ($ Amount)	Percent of Total
Residential	13,787,813,000	75.75%
Commercial	3,430,804,000	18.85%
Industrial	516,781,000	2.84%
Agricultural	14,212,000	0.08%
Religious	176,010,000	0.97%
Government	138,083,000	0.76%
Education	138,328,000	0.76%
Total	18,202,031,000	100.00%

3.0 COMBINED EFFECTS

The combined effects of wind, rain, and storm inundation will have a devastating impact on the critical infrastructure of Oahu. Most if not all of Honolulu International Airport (HNL)/Hickam Air Force Base (AFB) will be inundated. The velocity of storm surge will degrade the reef runway substructure and its functionality. Due to deep, fast moving water, the bridge to Sand Island will be severely damaged or destroyed, isolating Sand Island.

The DST also shows a significant portion of residential zoning in these high-impact areas. The south shore of Oahu is home to 489,395 residents and supports an additional 80,000 tourists on any given day. Wind speed-up factors may produce wind gusts over 200 mph. Most residential housing is of single-wall construction that will not withstand winds over 130 mph.

Within the storm inundation and flood zones for this study, there are approximately eight medical care facilities, eight emergency shelters, six fire stations, two water stations, two main port services facilities, one power facility, and numerous electrical transmission lines. See Figure 3.0-1 and the DST.

Within high wind gust zones (200+ mph) on Oahu, there are approximately 14 medical care facilities, 37 emergency shelters, eight fire stations, five water stations, two power generation facilities, numerous electrical transmission lines, and single wall construction residential housing. See Figure 3.0-2 and the DST.

Although nearshore models for flooding and inundation were not conducted for the west shore of Oahu, significant damage is expected at Campbell Industrial Park, Kalaeloa, and Barbers Point, causing pockets of isolation. The aforementioned areas store a significant percentage of the island's fuels, produce a considerable amount of the electricity, and house several manufacturing facilities. Wrap around wave energy and storm inundation is also expected to heavily damage the Windward shore, including Kaneohe Bay.

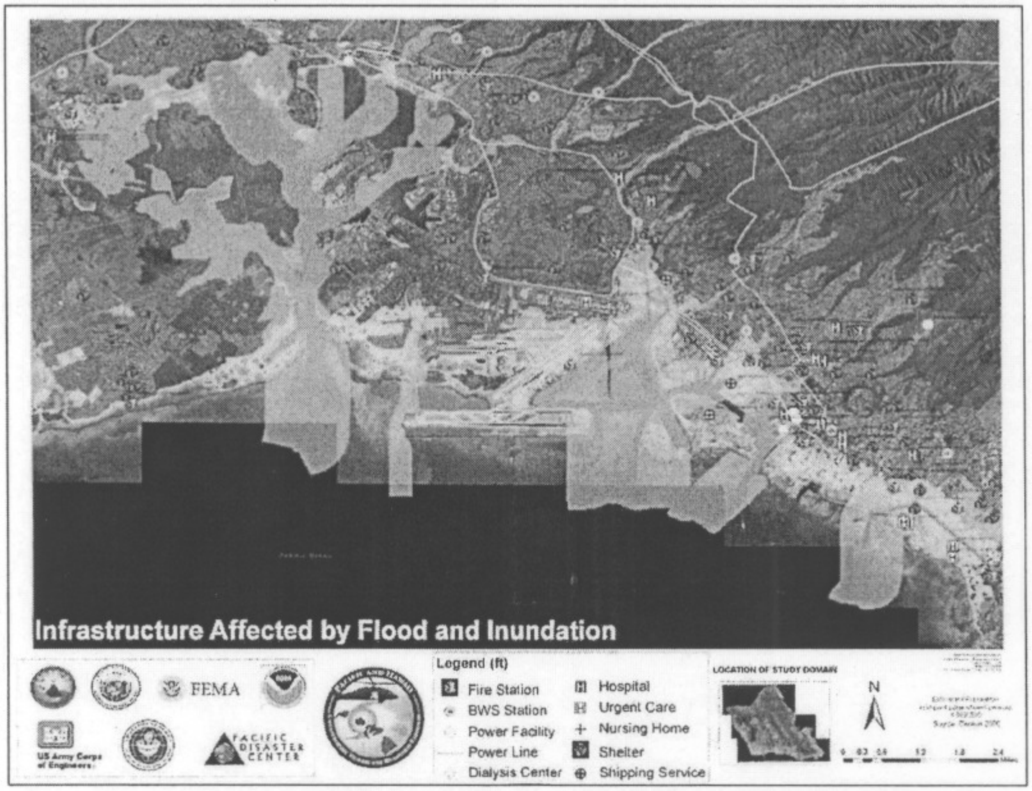

Figure 3.0-1: Key infrastructure subject to damage from flooding and storm inundation.

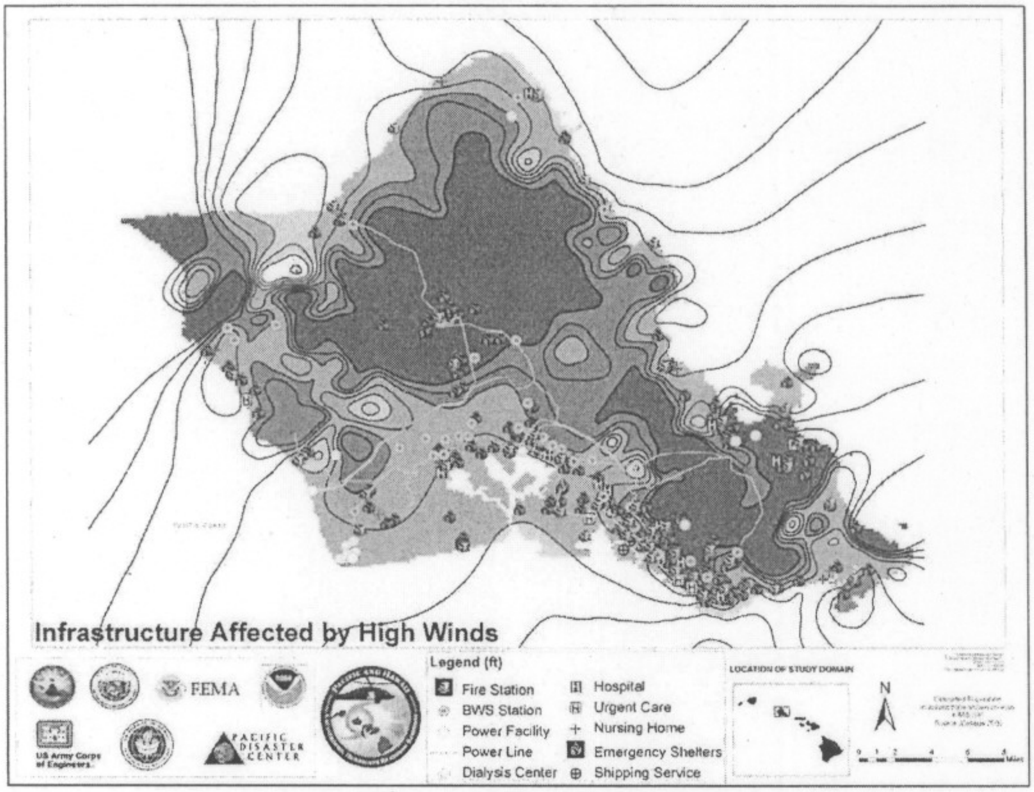

Figure 3.0-2: Key infrastructure subject to damage from high wind gusts.