



Geography 319

# Waves of Change The Role of Tsunamis in the Changing Built Landscape on Mokuola Island in Hilo Bay, Hawai'i

Holly Miller

## Introduction

Tsunamis, or seismic sea waves, have impacted Hawai'i since the islands formed millions of years ago. The archipelago's location in the middle of the Pacific Ocean makes it a prime location for the reception of tsunamis that have their sources along the rim of the Pacific. Most destructive tsunamis in Hawai'i can be traced to large undersea earthquakes off the coast of South America, along the Aleutian Islands, and near the Kamchatka peninsula. Since tsunamis spread out in a great circle from their epicenters, Hilo is particularly vulnerable to tsunamis due to its north-easterly orientation. The small island of Mokuola in Hilo Bay, often called 'Coconut Island', is especially prone to the destructive forces of these tsunamis. This is because the island is situated just off-shore where the energy in tsunami waves has had little chance to dissipate. All of the major tsunamis that have entered Hilo Bay have wreaked havoc on any structures built on Mokuola. Yet the people of Hilo continue to build on the island because of its culturally-significant and beautiful setting. Before Western contact, Mokuola was a place of refuge and place of healing and spirituality for Hawaiians. As society and culture changed in Hilo, other structures were built there. A small hospital was there, then bathhouses, a family home

for the island's caretakers, a sliding board and wooden diving pier, concrete reinforced walls, boat docks, a military barracks and recreation facilities, a wooden bridge, concrete diving platform, a large concrete and steel bridge, and finally a modern cinder-block bathroom and pavilion. While the culture and people of Hilo changed the built landscape of the island according to their needs or desires, powerful tsunamis were often the forces that erased the previous landscape so that a new one could be designed. Additionally, decisions about what to build, especially after people began to better understand the threat of tsunamis in Hawai'i, were made to mitigate the effects of future tsunamis. Land-use planning and disaster preparedness now play an important role in how the park is used and what structures exist there. This essay will outline what tsunamis are and how they form, why Mokuola is so vulnerable to them, what impacts they have on the island and people who use it, how tsunamis are predicted, and what land-use and hazard-reduction policies are in place at Mokuola.

## Tsunami Causes and Functions

There are several forces that can cause tsunamis. Undersea earthquakes are the most common cause, but tsunamis can be generated by volcanic eruptions and their associated pyroclastic flows, landslides, underwater landslides, and meteorite impacts. In all cases, a high-energy event displaces a large amount of water, which then spreads out from its source. Volcanically-produced tsunamis occur when an underwater volcano erupts into water, when an underwater caldera collapses, or when a near-shore volcano sends a large pyroclastic flow into the sea.<sup>1</sup> Landslides can cause tsunamis when materials on slopes become unstable and fail. This can result from disturbance by earthquake or volcanic eruption, storms and rain, or the eventual failure of a slope due to long-term

deposition of material.<sup>2</sup> Undersea landslides occur when slopes on the sea floor collapse due to some kind of disturbance or long-term build-up that reaches a stability threshold. Landslides can produce both remote-sourced tsunamis and local tsunamis, which cause destruction over a relatively small area. Meteorites can also cause tsunamis, though none have occurred in recorded history. However, meteorites have the potential to cause “mega-tsunamis,” or tsunamis that have wave amplitudes over 300 feet.<sup>3</sup> These waves could wash inland for hundreds of kilometers. It is theorized that an asteroid impact that caused the extinction of the dinosaurs 65 million years ago generated a mega-tsunami. Most of the tsunamis that impact Hilo Bay are generated by remote undersea earthquakes in the Aleutian Islands, the Kamchatka Peninsula, the Gulf of Alaska, and off the coast of South America. Therefore, it makes sense to focus primarily on undersea earthquakes as tsunami sources and their subsequent effects on Mokuola.

Not every undersea earthquake generates a tsunami. Generally, large undersea earthquakes with a magnitude of 6.5 or greater on the Richter scale have the potential to cause tsunamis, though two-thirds of destructive tsunamis in the Pacific have been generated by earthquakes with a magnitude of at least 7.5.<sup>4</sup> Earthquakes that cause tsunamis usually occur along oceanic subduction zones, or trenches, where the denser oceanic plate slides under the less dense continental plate.<sup>5</sup> The thrusting up, down, or even sideways movements of the seafloor in “tsunamigenic earthquakes” is typically associated with a shallow earthquake focus, and the resulting displacement of the seafloor by several meters can occur along long fault lines and over thousands of square miles.<sup>6</sup> When the seafloor shifting displaces the column of water directly above it, the energy from the earthquake is transferred to the water and “can propagate outward from the source at a speed of more than 1,000 km per hour depending on the depth of the water.”<sup>7</sup>

It is important to note that when a tsunami is generated, a series of waves moves out radially from the source, not just one single devastating wave. The typical wavelength, or the distance between crests, can measure from 50 to 500 kilometers, and wave periods, or the time between the arrival of the first and second wave crest, can range from 1.6 to 33 minutes. The largest wave in a tsunami may occur early in the series or late, which can give people a false sense of security when they observe a small initial wave and believe that the worst is over.

A tsunami in the deep ocean behaves very differently from a tsunami approaching shore. Since tsunami waves are not generated by wind action, their movement in the deep ocean stretches from the seafloor to the water’s surface.<sup>8</sup> Their speed of travel is directly related to the ocean’s depth as they pass. In deep waters, tsunamis can travel at more than 500 miles per hour but have a wave height of less than a meter.<sup>9</sup> This is why people on ships often do not sense tsunamis as they pass under them, and also why boat owners take their crafts far from shore when there is a tsunami threat. As tsunamis move into shallower waters, their velocity decreases, causing the energy in the wave to become compressed. A wave traveling at the same speed as a jet in the deep ocean will slow to 100-300 kilometers per hour across the continental shelf, and only 36 kilometers per hour when it reaches shore.<sup>10</sup> This causes a wave that may have had a height of less than a meter in the open ocean to become several meters high at shore. The exact way in which a tsunami arrives is controlled by the local bathymetry, or undersea topography, the directionality of the wave, and the magnitude of the generating event. Tsunamis can arrive like a quickly-rising and falling tide, like a series of waves breaking over one another, or as a wall of water.<sup>11</sup> Either the crest or the trough of the wave can arrive first. If the trough arrives, the ocean will recede drastically, often exposing the seafloor. This can be a warning for people near the shore. However, if the crest of the first

wave arrives first, there could be no warning whatsoever.

Tsunamis in Hawai'i can cause major destruction in some places and cause little to no damage in others just a few miles away. Hilo Bay and Mokuola are particularly vulnerable to tsunami damage due to a number of reasons. First, the local bathymetry and the shape of Hilo Bay determine how the waves will form. The water surrounding Hawai'i Island, due to the island's large size, is relatively shallow for quite a distance from shore. This means that tsunamis, when approaching the island, slow in velocity and increase in wave height. Hilo Bay, with its wide opening and funnel shape that narrows as it approaches shore, acts to amplify any approaching tsunamis. Second, Hilo Bay has little coral to absorb tsunami energy. The presence of coral reefs and other near-shore coarse topography can act to absorb the energy of the tsunami, lessening its effect on the shore nearby. Third, tsunamis can be amplified when their arrival coincides with the seiching rhythm of a bay.<sup>12</sup> A seiche is basically the natural oscillation, or the sloshing back-and-forth of a body of water. Whereas a bathtub might have a seiching period of just a couple of seconds, a bay might have a seiching period of minutes to hours.<sup>13</sup> Dudley writes that the "[t]he impressive wave heights tsunamis produce in Hilo Bay are at least partly related to the seiche effect."<sup>14</sup> Finally, Hilo Bay is geographically located in a prime position to receive tsunamis. Most tsunamis that affect Hilo are generated in the northern Pacific and along the coast of South America. The faults that these tsunamigenic earthquakes occur along are elliptically shaped with their bow facing south and west, respectively. When a tsunami is generated, "the major part of the tsunami energy is transmitted at right angles to the direction of the major axis, both toward the near shore and along a great circle path toward the shore on the opposite side of the ocean."<sup>15</sup> Hilo Bay's north-easterly facing orientation makes it especially susceptible to tsunamis generated

in these locations.

### **Tsunamis and the Changing Built Landscape at Mokuola**

Mokuola is situated just offshore in Hilo Bay with a maximum elevation of just a few feet above sea level, making its entire surface vulnerable to tsunamis. When tsunami damage is discussed, the term "run-up" is used to designate the farthest point that a tsunami will wash up on shore, while "inundation" is used to describe the maximum depth of the water above a normal sea level during the tsunami.<sup>16</sup> The entirety of Mokuola has fallen within tsunami run-up and inundation levels in all major tsunamis in recent history, and the built landscape at Mokuola has undergone several major changes necessitated by the destructive forces of these tsunamis. Depending on social needs and who had the means to make decisions about what would be built, the look and use of Mokuola has changed drastically over time.

Mokuola, in Hawaiian culture, is a place of healing. A rock just off its shore is believed to have healing powers, and people who are sick have come to Mokuola to swim around the rock in the hopes of healing their ailments. Any structures present on the island before Western contact were not recorded in the written record, but the site as place of healing stretched all the way into the late 19th century. It is not known if the Hawaiian beliefs about Mokuola actually determined the island to be an appropriate site for a hospital, but that is precisely the first structure known to be destroyed by a tsunami there. In a May, 1877 article in the Pacific Commercial Advertiser, Marshal Parke wrote, "The water swept completely over Cocoanut [sic] Island, and the hospital there has disappeared."<sup>17</sup> At this point in history, Hilo's society was changing. The state religion of Hawai'i had been abolished by Kamehameha II in 1819, and Western businessmen and missionaries were beginning to make up a significant part of Hilo's population. Mokuola became either crown or government property in

the 1848 land redistribution, but as the 1800s progressed, the Hawaiian monarchy lost its power to the Westerner-dominated government. Hawai'i became a U.S. territory in 1898, and control of Mokuola fell into the hands of the local government and the territorial government. A distinct separation between work and leisure had developed in Western society, and parks where leisure could take place became naturalized in Western landscapes. Mokuola, as a place both prone to destructive tsunamis and a beautiful setting away from the town center, was officially designated as a park in 1907 by the newly-incorporated County of Hawai'i. People often went to Mokuola for picnics and for swimming, but some Hawaiians continued to come to Mokuola for healing.

Bathhouses for swimmers and picnickers were erected on the island in the years following the 1877 tsunami. Later, Hawai'i County hired the Keli'ipio family to be the caretakers of the park, and the family built a private residence and boat dock on the island sometime shortly after the turn of the century. A sliding board and diving tower appear in pictures about 1918. According to Paul Keli'ipio, who took over the caretaker position after his mother died, the family was asked by the county to move from the island to a house on the adjacent shore, but the home stood there until 1923 when another tsunami destroyed all of the structures on the island. An excerpt from the Hawai'i Herald, 8 February, 1923, describes the damage:

Cocoanut [sic] Island was pretty well wrecked. The wave swept it completely. The old house formerly used by the keeper of the island, was turned completely around and swept seaward for a distance of about 20 feet and then laid flat on the ground. A tall cocoanut [sic] tree, directly in its path was snapped off at the ground. The bathhouses were also torn down and moved some 12 feet nearer the landing place.<sup>18</sup>

New bathhouses were built on the island following the 1923 tsunami, and the Keli'ipios continued to ferry park-goers between the mainland and the islet. However, when the United States entered World War II, the U.S. military took possession of the island and closed it to the public.

In 1942, Mokuola USO was established, and recreational and training facilities were constructed there for American soldiers. The facilities were officially opened to soldiers in 1943, and the military kept the island off-limits to the public until 1945.<sup>19</sup> The army constructed a pontoon bridge to the island as well, the first bridge to ever connect Mokuola to the adjacent shore.<sup>20</sup> When the island was finally turned over to the county in 1945, the pontoon bridge was put off-limits due to it being a "hazard to children and too costly to maintain."<sup>21</sup> Boat service between the island and the shore resumed until April 1, 1946 when a devastating tsunami once again destroyed all of the structures on Mokuola except for a concrete diving tower that is believed to have been constructed by the Army Corps of Engineers for training purposes.

A 7.3 magnitude earthquake south of Unimak Island in the Aleutian chain generated the 1946 tsunami that swept completely over Mokuola and continued onto shore, destroying businesses and homes, and took 96 lives in Hilo.<sup>22</sup> As mentioned, the shape of Hilo Bay and underwater bathymetry contributed to the destructive power of the waves. Additionally, a phenomenon known as a 'bore' is believed to have contributed to the waves' destruction at Hilo. A bore appears as a wall of water, which is created when the waves move through shallow water and begin to slow in velocity but increase in height. The waves in front move more slowly than those behind, which allow them to "pile up" as the distance between wave crests diminishes.<sup>23</sup> The waves reached 7.5 meters above normal sea level at Mokuola, as marked on a coconut palm standing on the island today. Although the setting of Hilo Bay largely enhanced the destruction of the

waves, it is believed that the breakwater that was completed about 1930 actually helped to mitigate the tsunami's effects by absorbing some of its energy.<sup>24</sup> On the same token, buildings that received the full force of the waves along the Hilo bay front absorbed much of the tsunami's energy, thereby reducing the waves' effects on buildings situated further back.<sup>25</sup> Following the tsunami, "seismic wave rehabilitation" funds were in part allocated for the reconstruction of park facilities and a new bridge at Mokuola.<sup>26</sup> The park's facilities were finally completed in 1949, and in 1951 a new bridge was constructed on the island. Just one year later, a tsunami generated near the Kamchatka peninsula swept completely over the island and destroyed the new park facilities.

After the 1946 tsunami, Hilo began to modify its approach to development and building design. The area along the bay front between Kamehameha Avenue and the ocean was re-designated a buffer zone where no businesses could be built.<sup>27</sup> Any remaining businesses were condemned and torn down, and trees were planted in the area to absorb the energy of future tsunamis. The highway along the waterfront was raised, and a warning system with sirens was put in place.<sup>28</sup> Mokuola naturally fell into the category of limited use areas, as it had historically been severely impacted by tsunamis. Its use as a park adhered to appropriate precautionary use of the site. However, the new buildings at Mokuola were not able to withstand the 1952 tsunami that once again destroyed all of the facilities there. A 1957 tsunami then damaged the bridge there, but repairs were made quickly and it remained open until the next major tsunami struck the island.

The May 22, 1960 tsunami was generated off the coast of Chile by an undersea earthquake with a magnitude between 8.25 and 8.5.<sup>29</sup> This time, a cohesive system of Pacific-wide seismographs and tidal gauge stations sent information to a disaster warning system in Hawai'i.<sup>30</sup> With so many tsunamis in recent history, Hilo's disaster-

preparedness agencies and government had made important land-use changes and were prepared with warning sirens and evacuation plans. However, 61 deaths still occurred, mostly due to people's unwillingness to heed warnings, combined with a recent change in the warning siren system. Just a few months before the 1960 tsunami, the warning system changed from a three-siren warning in which the first siren meant a warning was in effect; the second meant people should evacuate; and the third would sound just before the arrival of the first wave.<sup>31</sup> The new system had only one siren that meant "evacuate immediately." Clearly, not enough work had gone in to re-educating the public about tsunamis and the local warning systems in place. At Mokuola, the tsunami once again washed completely over the island, destroying all buildings and the new bridge there.<sup>32</sup> For three years, Mokuola was abandoned. In 1963, Hilo Boy Scouts cleared the island of weeds, and then in 1966 the 4H club once again cleaned up the island and cleared it of weeds.<sup>33</sup> Funds were eventually allocated for a major restoration project of the island, including a new metal and concrete bridge, and new concrete walls to slow erosion.<sup>34</sup> By 1969 the bridge was completed and the park was re-opened to the public.

The park facilities constructed following the 1960 event remain in place as there have been no major tsunamis to affect Mokuola since then. The bridge and buildings were designed to withstand future tsunamis. The bathhouse is constructed of cinder-block with drainage openings around its base for water to flow in and out of. As Shepard wrote in 1950, "experience has shown that well-constructed reinforced concrete will sustain little if any structural damage."<sup>35</sup> Drainage systems have been put in place on the island, and the pavilion has a concrete slab base and is open so that tsunamis can flow through. The bridge is situated high over the water and is composed of metal and concrete. The only structure that stands on the island today that was there before 1960 is the concrete diving

platform, which first appeared in photographs of soldiers using it for training purposes during WWII. This concrete structure testifies to the power of tsunamis that wiped out anything composed of weaker materials. While concrete, cinder-block and metal are surely more resistant to tsunamis than wood, they are not completely immune to the powerful forces of large tsunamis. The future could bring destruction to the current facilities as well, ushering in a new round of rebuilding. It is clear, however, that Hilo's residents choose to build at Mokuola because of its ideal setting for a park. Considering our modern understanding of tsunami risk in Hawai'i, a park is the only appropriate use of the place as deemed by the local planning association.

### **Tsunami Hazard Mitigation and Forecasting**

Although Thomas Jaggar of the Hawai'i Volcano Observatory warned authorities of the possibility of a tsunami in 1923 (which did come to pass), no official warning and detection system was put in place until after the 1946 tsunami. The United States Coast and Geodetic Survey was asked to develop a system that could "1) detect rapidly and accurately the location of each earthquake; 2) determine the actual existence of a tsunami; and 3) calculate the expected time of arrival of the tsunami in the island."<sup>36</sup> The Seismic Sea Wave Warning System (SSWWS) was established in 1949, and used several seismograph stations around the Pacific and on the U.S. mainland to triangulate the exact location of earthquakes' epicenters. Tidal gauges were put in place around the Pacific to detect tsunami waves, and the Tsunami Warning Center was established as the program's headquarters at the Honolulu Geomagnetic Observatory.<sup>37</sup> When tsunamis were detected, the center issued warnings to civil and military authorities. In Hilo, a siren warning system was put in place and evacuation maps were created. Warnings were issued over the radio. A major rezoning project identified most of the bay front and vulnerable areas as a buffer strip where no

businesses or homes could be built.

Although the warning system functioned correctly during the 1960 tsunami, many problems were identified, and changes were made following the disaster. Detailed and updated tsunami inundation and evacuation maps were designed. Further rezoning of vulnerable areas was conducted by the newly-established Hawai'i Redevelopment Agency under Project Kaiko'o.<sup>38</sup> This project expanded the bay front buffer zone and determined that lands falling within buffer areas could have limited use, as defined by the project. Parkland and greenbelt is the most common land use, of which Mokuola falls under. The project also filled certain areas to increase their mean elevation, making the areas less susceptible to tsunami flooding. The Small Business Administration made loans available to local business people to help them rebuild. The United States Congress also made funds available for construction of tsunami protection barriers with recommendations, including two rockfill barriers and a land dike.<sup>39</sup> An elevated highway was constructed along Hilo's bay front, which protects the downtown area from storm surges and moderate tsunamis.<sup>40</sup> The U.S. Army Corps of Engineers suggested building a 22-foot high seawall that runs from the Wailuku River all the way to Mokuola, although this suggestion never came to fruition.<sup>41</sup> This particular suggestion would have undoubtedly changed the character of the park significantly.

The need for better public education about tsunamis was illustrated by the 1960 tsunami and its effects. Had the public been more knowledgeable about how to react to tsunami warnings, the 61 deaths that occurred could have been prevented. One of the causes of confusion was the change in the warning system, as mentioned. However, several studies show that people are generally unaware of what actually occurs during a tsunami. People often believe it consists of just one wave, or that the largest wave will always come first. They don't understand that

every tsunami is unique and can vary greatly in how it will affect coastlines. People may not understand where their local evacuation areas are, or where to go when a tsunami warning is issued. Key terms used to describe tsunamis like run-up and inundation are often not understood. Mild tsunamis in 1952 and 1957 caused many people to believe that the 1960 tsunami would also be mild, even with the memory of the devastating 1946 tsunami in many people's minds. Dudley writes that the tourist industry in Hawai'i is reluctant to educate their guests about tsunamis for fear that the information might scare guests away.<sup>42</sup> Warning systems can only work when the public understands what to do when a warning is issued.

Today, tsunami education is important in Hilo. Several agencies, including the National Atmospheric and Oceanic Administration (NOAA), the Pacific Tsunami Museum, the Pacific Disaster Center, and Hawai'i Civil Defense, all work to bring education programs to schools, businesses, communities, and to media outlets like the internet, television and radio. Hawai'i phonebooks have tsunami evacuation information and maps in the front, and new information and technologies are consistently updated. Several websites and publications detail how tsunamis behave, how people can be prepared for disasters, and what one should do during a tsunami warning. Hawai'i Civil Defense designates shelters, has evacuation plans, and puts up manned roadblocks around danger areas.<sup>43</sup> Monthly tests are performed on the tsunami warning sirens around Hilo, which can be heard along all parts of Hilo's coast, including Mokuola.

Tsunamis are detected in much the same way as they were in 1960, with the exception of several new tsunami detection buoys that line the Pacific Rim.<sup>44</sup> These buoys are attached to an anchored pressure sensor on the seafloor. When a tsunami is detected, the buoys relay data to NOAA's Tsunami Warning Centers around the Pacific, and these centers then send this information to civil

defense organizations. Any earthquake with a magnitude of 7.5 or greater that occurs in an area that could generate a tsunami will automatically generate a tsunami watch. If a tsunami is then detected, the warning is issued.<sup>45</sup> If a tsunami warning is necessary, the Emergency Alert System is notified, which then broadcasts warning messages over television and radio. Hilo's sirens will sound three hours prior to the expected arrival of the first wave, which is a call to listen to the radio for emergency messages. The siren will sound again two hours, one hour, and thirty minutes before the expected arrival of the first wave.<sup>46</sup> People can also subscribe to mobile phone alerts for tsunami warnings.

## **Conclusion**

On Mokuola there is a coconut palm with small plaques that indicate the maximum wave height of tsunamis that washed over the island. For those who have not experienced a tsunami first-hand, the 1946 marker 26 feet up the tree allows for a deeper understanding and respect for tsunamis. Standing at the base of the tree, it seems almost impossible that a wave that high could crash over the islet. Although no major tsunamis have struck Hilo since 1960, it is undoubtedly just a matter of time before they do. Downtown Hilo may be able to stave off much of the damage due to hazard mitigation actions taken like designating the buffer zone and building rock walls, but Mokuola has little protection. Its beautiful setting and proximity to the hotel area demands that no major protective structures be built that would threaten the aesthetic quality of the island. This means that the structures built there now and in the future must take into account the likelihood that a major tsunami will once again crash completely over Mokuola. With what we now know about tsunamis, it is unlikely that the zoning and nature of land use at Mokuola will change like it has in the past. While a hospital will likely never be built there again, its historic presence and all of the other subsequent changes in the built landscape

have much to tell us about how we have come to live with and mitigate the effects of tsunamis in Hawai'i.

## Footnotes

- <sup>1</sup> Walter C. Dudley and Min Lee, *Tsunami!* (Honolulu: The University of Hawai'i Press, 1998), 80.
- <sup>2</sup> *Ibid*, 72.
- <sup>3</sup> *Ibid*, 314.
- <sup>4</sup> Edward Bryant, *Tsunami: The Underrated Hazard* (Cambridge: Cambridge University Press, 2001), 13 and 136.
- <sup>5</sup> Walter C. Dudley and Min Lee, *Tsunami!* (Honolulu: The University of Hawai'i Press, 1998), 61-62.
- <sup>6</sup> Walter C. Dudley and Min Lee, *Tsunami!* (Honolulu: The University of Hawai'i Press, 1998), 61 and Edward Bryant, *Tsunami: The Underrated Hazard* (Cambridge: Cambridge University Press, 2001), 136.
- <sup>7</sup> James F. Lander and Patricia A. Lockridge, *United States Tsunamis (Including United States Possessions): 1690-1988* (Boulder: National Geophysical Data Center, 1989), 2-3.
- <sup>8</sup> Walter C. Dudley and Min Lee, *Tsunami!* (Honolulu: The University of Hawai'i Press, 1998), 90.
- <sup>9</sup> *Ibid*, 90.
- <sup>10</sup> Edward Bryant, *Tsunami: The Underrated Hazard* (Cambridge: Cambridge University Press, 2001), 28.
- <sup>11</sup> Pacific Disaster Center, *Tsunami*, <http://www.pdc.org/iweb/tsunami.jsp?subg=1>.
- <sup>12</sup> Walter C. Dudley and Min Lee, *Tsunami!* (Honolulu: The University of Hawai'i Press, 1998), 92.
- <sup>13</sup> *Ibid*, 92.
- <sup>14</sup> *Ibid*, 93.
- <sup>15</sup> James F. Lander and Patricia A. Lockridge, *United States Tsunamis (Including United States Possessions): 1690-1988* (Boulder: National Geophysical Data Center, 1989), 3.
- <sup>16</sup> Walter C. Dudley and Min Lee, *Tsunami!* (Honolulu: The University of Hawai'i Press, 1998), 97
- <sup>17</sup> Marshal Parke, "Tidal Wave at Hilo, with Loss of Lives and Property," *Pacific Commercial Advertiser*, May 26, 1877, XXI no. 48.
- <sup>18</sup> "Cocoanut Island Suffers," *Hawai'i Herald*, February, 8, 1923, XXVI no. 27, 5.
- <sup>19</sup> Kent Warshauer, "Visiting Coconut Island was once no easy feat," in *The Riddle of the Relic* (Hilo: Memories of Hawai'i LLC, 2006), 417.
- <sup>20</sup> *Ibid*, 417.
- <sup>21</sup> *Ibid*, 417.
- <sup>22</sup> James F. Lander and Patricia A. Lockridge, *United States Tsunamis (Including United States Possessions): 1690-1988* (Boulder: National Geophysical Data Center, 1989), 38 and F.P. Shepard, G.A. MacDonald, and D.C. Cox, *The Tsunami of April 1, 1946* (Berkeley and Los Angeles: University of California Press, 1950), 404.
- <sup>23</sup> Walter C. Dudley and Min Lee, *Tsunami!* (Honolulu: The University of Hawai'i Press, 1998), 94.

- <sup>24</sup> Hilo Technical Advisory Council, Protection of Hilo From Tsunamis (Hawai'i County, 1962), 6.
- <sup>25</sup> Hilo Technical Advisory Council, Protection of Hilo From Tsunamis (Hawai'i County, 1962), 7.
- <sup>26</sup> Kent Warshauer, "Visiting Coconut Island was once no easy feat," in *The Riddle of the Relic* (Hilo: Memories of Hawai'i LLC, 2006), 417.
- <sup>27</sup> Hilo Technical Advisory Council, Protection of Hilo From Tsunamis (Hawai'i County, 1962), 7.
- <sup>28</sup> *Ibid*, 7.
- <sup>29</sup> Hawai'ian Volcano Observatory, "The 1960 Tsunami, Hilo," [http://hvo.wr.usgs.gov/volcanowatch/1994/94\\_05\\_20.html](http://hvo.wr.usgs.gov/volcanowatch/1994/94_05_20.html).
- <sup>30</sup> Hilo Technical Advisory Council, Protection of Hilo From Tsunamis (Hawai'i County, 1962), 7.
- <sup>31</sup> Walter C. Dudley and Min Lee, *Tsunami!* (Honolulu: The University of Hawai'i Press, 1998), 145.
- <sup>32</sup> Kent Warshauer, "Tsunami wreak havoc on Coconut Island," in *The Riddle of the Relic* (Hilo: Memories of Hawai'i LLC, 2006), Kent Warshauer, 418.
- <sup>33</sup> *Ibid*, 419.
- <sup>34</sup> *Ibid*, 419.
- <sup>35</sup> F.P. Shepard, G.A. MacDonald, and D.C. Cox, *The Tsunami of April 1, 1946* (Berkeley and Los Angeles: University of California Press, 1950), 466.
- <sup>36</sup> James F. Lander and Patricia A. Lockridge, *United States Tsunamis (Including United States Possessions): 1690-1988* (Boulder: National Geophysical Data Center, 1989), 5.
- <sup>37</sup> Pacific Tsunami Warning Center, "PTWC History," <http://www.weather.gov/ptwc/history.php>.
- <sup>38</sup> Hilo Technical Advisory Council, Protection of Hilo From Tsunamis (Hawai'i County, 1962), 7.
- <sup>39</sup> Hilo Technical Advisory Council, Protection of Hilo From Tsunamis (Hawai'i County, 1962), 7.
- <sup>40</sup> U.S. Army Corps of Engineers, *Review Report on Survey of Hilo Harbor, Island of Hawai'i*, T.H.(Honolulu: U.S. Army Engineer District, 1957), 20.
- <sup>41</sup> *Ibid*, 23.
- <sup>42</sup> Walter C. Dudley and Min Lee, *Tsunami!* (Honolulu: The University of Hawai'i Press, 1998), 334.
- <sup>43</sup> Hawai'i Civil Defense, *Tsunami Evacuation Hawai'i Map 1: Hilo (Part 1)*, <http://www.pdc.org/DisasterInfo/Shelters/CDmaps/HawaiiCounty/H-map01.html>.
- <sup>44</sup> National Oceanic and Atmospheric Administration, *How does the tsunami warning system work?*, [http://www.tsunami.noaa.gov/warning\\_system\\_works.html](http://www.tsunami.noaa.gov/warning_system_works.html).
- <sup>45</sup> Pacific Tsunami Museum, *Frequently Asked Questions*, <http://www.tsunami.org/faq.html>.
- <sup>46</sup> Walter C. Dudley and Min Lee, *Tsunami!* (Honolulu: The University of Hawai'i Press, 1998), 177.

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